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NEXT GENERATION WEATHER RADAR

ALGORITHM REPORT

COMMERCE · DEFENSE · TRANSPORTATION
NEXRAD
NEXT GENERATION WEATHER RADAR

December 1985

Prepared By

The NEXRAD Joint System Program Office

Next Generation Weather Radar

(NEXRAD)

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MAJOR REVISIONS SINCE MAY 1984

Preface and Introduction

1. In the introduction all occurrences of the word "contractors" has been changed to "contractor".

2. Language in the preface and introduction which indicated all algorithms were subject to future changes/enhancements has been modified to indicate that Category 1 algorithms are not candidates for significant changes/enhancements whereas certain Category 2 algorithms are.

3. Paragraph 1.4.1.a has been modified to indicate that the algorithm volume scans are described as being processed from the bottom up for clockwise antenna rotation.

4. Paragraph 1.4.1.i has been added regarding the resolution of arc tangent functions to the correct quadrant.

PREFACE

The automation of meteorological and hydrological analyses is a NEXRAD requirement. This report presents the algorithms the Government has developed (or is still developing) to meet that requirement.

While this report represents the current status of NEXRAD algorithms, it is recognized that in the case of some algorithms improvements, modifications, corrections, etc., remain to be made. During the life of the NEXRAD system (from acquisition through operational use), the Government expects to modify the algorithms defined in this report and to develop new algorithms. The full benefits of the NEXRAD system can only be realized through this process of enhancement. Thus, the design of the NEXRAD system must allow for the modification, addition, and deletion of algorithms. In this way the Government expects the NEXRAD system to keep pace with future advancements in the processing of weather radar data.

It is essential that all of the NEXRAD algorithms be reviewed and tested for both scientific validity and operational usefulness. This report includes algorithms which have been adequately reviewed and tested and are ready for contractor implementation with minimum risk. In order to provide the contractor information about possible future enhancements, this report also contains algorithms which are not ready for implementation.

Besides serving the contractor's needs, this report will be used to give the algorithms a wider distribution for scientific review and comment.

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SECTION 1.0

Introduction to NEXRAD Algorithm Report

1.0 INTRODUCTION

The Next Generation Weather Radar (NEXRAD) system design must automate as much of the data acquisition and data assessment process as possible. This is a basic user requirement. The NEXRAD system must provide the principal users with rapid and reliable identification of significant weather phenomena, and this identification must be automated to the maximum extent possible, consistent with the objectives of high probability of detection and low false alarm rate.

The technology to meet this "automation" requirement exists primarily as techniques within the research community. The NEXRAD Joint System Program Office (JSPO) is responsibile for acquiring and adapting these techniques as necessary to meet NEXRAD needs, and transferring the modified techniques (in the form of algorithms) to the NEXRAD system contractor for use in system design, validation, and production.

1.1 Algorithm Philosophy

The NEXRAD system acquisition process follows the guidance given in Office of Management and Budget Circular A-109. The A-109 approach is designed to make the most of the technical expertise that exists within industry. However, the Government has determined that the meteorological and hydrological analysis techniques necessary were only available within the Government. Thus, the Government has assumed responsibility for providing those meteorological and hydrological algorithms to the system contractor. The contractor will implement these algorithms into a real-time system.

The algorithms were documented in a standardized format based on the Documentation Standards Handbook (DSH). This approach defines the algorithms in functional terms and removes implementation dependencies that result from certain configurations or programmer biases. The process of identification, acquisition, and validation of algorithms by the JSPO will continue with the documentation and validation of new algorithms. This incremental approach results in

- System flexibility,
- System growth capability, and
- A modular design.

These characteristics are essential to the usefulness and life of the system.

While some uncertainties remain in some algorithms, the information available is sufficient to ensure successful implementation of the selected algorithms. In part, this results from documentation of most of the algorithms from software implemented in R&D systems. The results of continuing R&D studies will enhance both algorithm development efforts and the resulting technology transfer.

All the algorithms came from techniques originating in research and development programs. The documentation process produced a functional specification which provides the system contractor with the scientific requirements free of any implementation-dependent details. The link between the meteorologists and hydrologists and the systems analysts and computer scientists is provided by the DSH procedures. The DSH provides a communication link by enabling both of these groups to "speak the same language," i.e., both groups understand the logic and application of the algorithms.

1.2 Scope and Objectives of this Report

The JSPO prepared this report to provide the system contractor with information on the algorithms to be included in NEXRAD's initial operational capability and on candidates for future enhancements. This report will also provide a vehicle for wider distribution of the NEXRAD algorithms for scientific review and comment.

1.3 Algorithm Categories

NEXRAD algorithms can be divided into three categories:

Category 1: The algorithms to be implemented by the system contractor during the Limited Production and Production Phases are:

Algorithm	Version Number
MESOCYCLONE DETECTION	[002/33]
STORM TRACKING	[004/26]
STORM CENTROIDS	[005/45]
VERTICALLY-INTEGRATED LIQUID WATER	[006/24]
VELOCITY AZIMUTH DISPLAY	[007/29]
STORM POSITION FORECAST	[008/25]
STORM STRUCTURE	[009/44]
HAIL	[012/35]
ECHO TOPS	[013/17]
SEVERE WEATHER PROBABILITY	[015/18]
PRECIPITATION PREPROCESSING	[017/39]
PRECIPITATION RATE	[018/27]
PRECIPITATION ACCUMULATION	[019/29]
PRECIPITATION ADJUSTMENT	[020/25]
PRECIPITATION PRODUCTS	[021/22]

STORM SEGMENTS	[022/23]
TURBULENCE	[023/10]
TVS DETECTION	[026/10]
COMBINED SHEAR	[033/03]

Category 2: The algorithms that have been documented and will not be implemented by the contractor, but are candidates for implementation at the Operational Support Facility (OSF) are:

Algorithm	Version Number
TRANSVERSE WIND	[011/27]
MODIFIED VELOCITY VOLUME PROCESSING	[016/25]
DIVERGENCE DETECTION	[024/10]
SECTORIZED UNIFORM WIND	[027/04]
GUST FRONT DETECTION	[029/03]
FLASH FLOOD PRECIPITATION PROJECTION	[030/05]
FLASH FLOOD POTENTIAL ASSESSMENT	[031/03]
CROSS CORRELATION TRACKING	[034/03]

Category 3: There are a number of unfilled operational requirements and technical needs for which no suitable algorithms have been documented as follows:

Icing
Mesocyclone/Tornado Vortex Detection
Tropical Cyclone
Downburst/Microburst
Modified Version of Storm Position Forecast
Storm Surge
Generalized Severe Convection Precursors
Rain Versus Snow Determination
Hail Size Determination
Snow Accumulation
Products for Central Weather Facilities
Bird/Aircraft Strike Hazard

1.4 Implementation Considerations

1.4.1 Documentation Conventions

Although the JSPO's intent was to document the NEXRAD algorithms in a PDL that was transparent to the implementation, it was not possible to do this in all cases. In order to document the algorithms, certain conventions were required to consistently and logically describe the processing. These conventions were not necessarily desirable in a specific algorithm implementation. For example, a coordinate system must be selected before trigonometric calculations can be specified; however, the calculations could be done equally well in another coordinate system if correctly transformed. As long as the display outputs are correct, internal calculations may be modified for speed or efficiency.

Other algorithm documentation conventions include:

a. Volume scans are described as being processed in sequence from the bottom up, with clockwise antenna rotation.

b. Many algorithms are described in terms of specific numbers or sizes of sample volumes as a unit of computation. These require adjustment to the sampling parameters of the selected radar.

c. Algorithm output resolution sometimes reflects either an initial implementation or an arbitrary choice. These may require adjustment for the selected display product.

d. Data quality checks may be indicated with the algorithm, particularly if the algorithm is sensitive to certain data errors. The data quality check may be implemented either as part of the algorithm or in previous processing.

e. Data units were selected somewhat arbitrarily, and are not necessarily optimal for final output and/or display.

f. Processing steps and equations are listed in logical order, not optimized for real-time processing.

g. Equations have not been combined or analytically solved for optimum processing.

h. Outbound Doppler velocities are designated as positive.

i. In algorithms using arc tangent, the computations are to be made such that the resultant angles are placed in the quadrant consistent with the signs of the numerator and denominator.

The contractor may modify the algorithms to improve efficiency without degrading the output. In each case, a description of the deviation shall be submited to the JSPO.

1.4.2 Data Quality Control

Many of the algorithms contain specific data quality checks. As noted under Implementation considerations, these may alternatively be done in pre-processing. For other algorithms, explicit quality checks are not listed, but accurate base data are required for proper algorithm performance. For example, the MESOCYCLONE

DETECTION (002) algorithm requires that range and velocity folding be removed from base velocity data before it operates on the data. Testing has shown that velocity folding can severely degrade the performance of this algorithm.

Although the net effect is not usually as dramatic with reflectivity contamination, certain algorithms suffer from ground clutter and anomalous point returns. For example, return from an aircraft in a moderate shower will cause a false high maximum reflectivity value to be assigned. Also, when the STORM STRUCTURE (009) algorithm is using the maximum reflectivity in a chosen volume, anomalous point target values must be removed prior to compositing. For the Precipitation (017-021) algorithms, reflectivity accuracy is extremely critical.

In the event that pre-processing does not properly control the base data quality, additional processing steps will be needed within the algorithm.

1.5 Algorithm Development and Implementation

As indicated in Figure 1, the operating agencies (DOC, DOT and DOD) are responsible for both the development and implementation of algorithms. On the development side, they provide R&D funds to such R&D agencies as the National Severe Storms Laboratory (NSSL), Lincoln Lab and the Air Force Geophysics Laboratory (AFGL). These agencies investigate the state of science and technology, develop a prototype algorithm and then refine, test and change it.

On the implementation side, the operating agencies provide joint procurement funds to the Next Generation Weather Radar Joint System Program Office (NEXRAD JSPO). The NEXRAD JSPO establishes NEXRAD's technical needs and then monitors the work at the R&D agencies to determine whether their algorithms are applicable to those technical needs and whether, in view of the NEXRAD design, it would be feasible to implement them. If so, the NEXRAD JSPO documents the algorithm in the Algorithm Report. The Interim Operational Test Facility (IOTF) displays the algorithm and tests it operationally. The Program for Regional Observing and Forecasting Services (PROFS) validates the algorithm by coding it from the algorithm enunciation language (AEL) and verifies that the algorithm performs acceptably. Finally, the algorithm is frozen and incorporated into the NEXRAD system. Category 1 algorithms will be incorporated by the contractor. Upon further development, selected Category 2 and 3 algorithms will be incorporated by the Operational Support Facility (OSF).

ALGORITHM DEVELOPMENT
&
IMPLEMENTATION

OPERATING AGENCIES

IMPLEMENTATION	DEVELOPMENT
Procurement Funds	Agency R & D Funds
NEXRAD JSPO	R & D AGENCIES
Establish Technical Need	Investigate State of Science & Technology
Monitor R & D	
Assess Applicability & Feasibility	Develop Algorithm
Document in Standard Format	Refine, Test, Change Algorithm
Develop Displays (IOTF)	
Test Operationally (IOTF)	
Validation and Verification (PROFS)	
"Freeze" Algorithm	
Incorporate into the NEXRAD system	

Figure 1

SECTION 2.0

NEXRAD Algorithm Descriptions

MESOCYCLONE DETECTION
ALGORITHM DESCRIPTION

NX-DR-03-002/33

MAJOR REVISIONS SINCE MAY 1984

Mesocyclone Detection (002)

1. All algorithms appearing in the May 1984 report have undergone the following changes:

    a. Editorial and typographical changes.

    b. Explicit declaration of data element precision.

    c. Renaming of data element names and symbols to achieve unique naming.

    d. Data Dictionary changes resulting from other changes.

2. Clarified loop 2.0 to remove possibility of more than one interpretation in the process of identifying 3-dimensional vortices. This clarification ensures the previous elevation angle will always be defined.

3. Corrected symbolic formulas for FEATURE CENTER POSITION, DIAMETER (Azimuthal), DIAMETER (Momentum Azimuthal) and HEIGHT (Feature Center).

4. Corrected IF THEN ELSE construct involving RANGE (Slant) in section 1.4.1. Without this correction some symmetric mesocyclones would not be detected.

5. Deleted WRITE (maximum SHEAR (Tangential)).

6. Added WRITEs for the following: Number of FEATUREs, DIAMETER (Radial), DIAMETER (Azimuthal), average MOMENTUM (Angular), HEIGHT (Feature Center), FEATURE CENTER POSITION and FEATURE EXTREMA.

7. Changed FEATURE TYPE to VORTEX TYPE

8. ASSIGN ID and WRITE ID were added to provide identification for each mesocyclone.

9. IF-THEN-ELSE construct in section 1.2.1 modified.

1.0 PROLOGUE

1.1 FUNCTIONAL DESCRIPTION

The MESOCYCLONE DETECTION algorithm utilizes pattern recognition techniques to detect mesocyclones. This technique defines a process used for searching through Doppler velocity data for symmetric regions of large azimuthal shear. The MESOCYCLONE DETECTION algorithm is based on the extraction of significant attributes which characterize mesocyclones.

The MESOCYCLONE DETECTION algorithm locates mesocyclones where a mesocyclone is defined as a three-dimensional region in a storm which rotates (usually cyclonically), and is closely correlated with severe weather. This algorithm uses the systematic procedure described herein. The first step is to search for a consistent increase of Doppler velocity in the azimuthal direction at a constant range (for clockwise antenna rotation). A consistent decrease of Doppler velocity is required for counterclockwise antenna rotation. (Note: The current AEL is written for clockwise antenna rotation only otherwise a "pattern vector" would be formed when a run of increasing or decreasing Doppler velocity ends.) A "pattern vector" contains seven components: the slant range, the azimuth angles at both ends of the run, the Doppler velocities that correspond to those azimuth angles at the slant range, and the SHEAR(Tangential) and MOMENTUM(Angular). A pattern vector which does not have the magnitudes of angular momentum and azimuthal shear typical of mesocyclones is discarded. The remaining pattern vectors are consolidated to form "features". A "feature" is a set of pattern vectors in a close proximity. If a feature is too small it is discarded. If a feature is sufficiently large and not symmetrical, it is classified as a shear region. Sufficiently large, symmetric shear regions are characteristic of mesocyclones. If these regions are in close vertical proximity, a mesocyclone is identified. Shear regions in close vertical proximity identify 3-D shear regions. The remaining features characterize uncorrelated shear.

1.2 SOURCE

The MESOCYCLONE DETECTION algorithm was developed at the National Severe Storms Laboratory, Norman, Oklahoma, by Larry Hennington. Significant attributes of mesocyclones have been compiled by Hennington and Burgess (1981), referenced below.

REFERENCES

Staff of JDOP, 1979: Final Report on Joint Doppler Operational Project (JDOP) 1976-1978. NOAA Tech. Memo. NSSL-86, March 1979, 84 pp.

Hennington, L.D., and D.W. Burgess, 1981: Automated recognition of mesocyclones from single Doppler radar data. Preprints 20th Conf. Radar Meteor., Boston, Amer. Meteor. Soc., 704-706.

Zrnic', Dusan S., D.W. Burgess and Y. Gal-Chen, 1984: Automated Detection of Mesocyclonic Shear Test Results. NEXRAD JSPO publication, January 1984, 51 pp.

1.3 PROCESSING ENVIRONMENT

Data input to the MESOCYCLONE DETECTION algorithm must be preprocessed for velocity unfolding and elimination of ground clutter. At any time, Doppler velocities for two consecutive radials of data are stored for processing.

2.0 INPUTS

2.1 IDENTIFICATION

AZIMUTH = Azimuthal position, in radians.

ELEVATION = Elevation angle, in radians.

RADIUS (Earth) = The radius of the Earth (6371), in kilometers.

RANGE (Slant) = The slant range to the center of a SAMPLE VOLUME, in kilometers.

SAMPLE VOLUME = A data sample volume whose dimensions are 1 degree in azimuth, 0.25 km in range, and 1 degree in depth (perpendicular to the radar beam).

THRESHOLD (Feature Height) = A value that represents the maximum height of possible mesocyclone FEATUREs (8), in kilometers.

THRESHOLD (High Momentum) = A value which represents the minimum magnitude of angular momentum expected in a mesocyclone in the presence of low shear (540.0), in km^2/hr.

THRESHOLD (Radial Distance) = A value which represents the maximum distance in the radial direction between PATTERN VECTORs within the same FEATURE (0.75), in kilometers.

THRESHOLD (Mesocyclone-High Shear) = A value which represents the minimum magnitude of shear expected in a mesocyclone in the presence of low angular momentum (14.4), in 1/hr.

THRESHOLD (Low Momentum) = A value which represents the minimum magnitude of angular momentum in a mesocyclone (180.0), in km^2/hr.

THRESHOLD (Mesocyclone-Low Shear) = A value which represents the minimum magnitude of shear expected in a mesocyclone (7.2), in 1/hr.

THRESHOLD (Mesocyclone Azimuth) = A value that represents the maximum tangential separation of PATTERN VECTORs to be considered part of the same FEATURE (0.034), in radians.

THRESHOLD (Pattern Vector) = A value which represents the minimum number of PATTERN VECTORs required to build a FEATURE (10.0).

THRESHOLD (Far Maximum Ratio) = A maximum value which represents the upper bound of a range of values related to the ratio of radial and azimuthal diameters of a FEATURE at ranges further than THRESHOLD (Range) (4.0).

THRESHOLD (Far Minimum Ratio) = A minimum value which represents the lower bound of a range of values related to the ratio of radial and azimuthal diameters of a FEATURE at ranges further than THRESHOLD (Range) (1.6).

THRESHOLD (Maximum Ratio) = A maximum value which represents the upper bound of a range of values related to the ratio of radial and azimuthal diameters of a FEATURE at ranges closer than THRESHOLD (Range) (2.0).

THRESHOLD (Minimum Ratio) = A minimum value which represents the lower bound of a range of values related to the ratio of radial and azimuthal diameters of a FEATURE at ranges closer than THRESHOLD (Range) (0.5).

THRESHOLD (Range) = A variable that represents the range at which long range symmetry criteria take effect, in kilometers (140.0 km).

VELOCITY (Doppler) = Doppler velocities in a SAMPLE VOLUME, in km/hr.

2.2 ACQUISITION

AZIMUTH and ELEVATION are obtained by direct measurement of the radar antenna pointing direction.

VELOCITY (Doppler) is acquired by direct radar measurements.

RADIUS (Earth) is a physical constant.

SAMPLE VOLUME is a direct result of the radar parameters chosen at the time of observation. The sample volumes will still be variable depending on range of observation because the radar beam is diverging.

RANGE (Slant) is acquired by direct radar measurements.

All the thresholds identified in Section 2.1 are site-adaptable parameters used by the algorithm. They are entered by the operator/user as input parameters or are embedded as tables in the algorithm implementation. They are being determined by the research community through further experimentation.

3.0 PROCEDURE

3.1 ALGORITHM

```
BEGIN ALGORITHM (MESOCYCLONE DETECTION)

1.0  DO FOR ALL (ELEVATIONS)
     1.1  DO FOR ALL (SAMPLE VOLUMEs of the first two
          adjacent radials.)
          1.1.1  COMPUTE (TENDENCY)
          END DO

     1.2  DO FOR ALL (remaining AZIMUTHs)
          1.2.1  DO FOR ALL (SAMPLE VOLUMEs)
                      COMPUTE (TENDENCY)
                      IF (TENDENCY at the previous AZIMUTH is less
                         than or equal to zero AND TENDENCY at the
                         current AZIMUTH is greater than zero)
                      THEN (the VELOCITY(Doppler) at the previous
                           AZIMUTH becomes beginning VELOCITY
                           (Doppler))
                      END IF
                      IF (TENDENCY at the previous AZIMUTH and this
                         RANGE(Slant) is greater than zero
                         AND TENDENCY at the current AZIMUTH at
                         this RANGE(Slant) is less than zero)
                      THEN (the VELOCITY(Doppler) at the previous
                           AZIMUTH becomes ending VELOCITY
                           (Doppler))
                        COMPUTE (MOMENTUM (Angular))
                        COMPUTE (SHEAR (Tangential))
                        IF (MOMENTUM (Angular) is greater
                           than the THRESHOLD (Low Momentum)
                           AND SHEAR (Tangential) is greater
                           than or equal to the THRESHOLD (Meso-
                           cyclone-High Shear)) or (MOMENTUM
                           (Angular) is greater than the THRES-
                           HOLD (High Momentum) AND SHEAR
                           (Tangential) is greater than the
                           THRESHOLD (Mesocyclone-Low Shear))
                           WRITE (PATTERN VECTOR)
                        END IF
                      END IF
                 END DO
           END DO
```

```
1.3  DO FOR ALL (PATTERN VECTORs)
     1.3.1  IF (PATTERN VECTOR centers are within
               THRESHOLD (Mesocyclone Azimuth) AND are
               within THRESHOLD (Radial Distance) of
               each other)
               THEN (Include PATTERN VECTORs as a part
                    of the same FEATURE)
                    (Add PATTERN VECTOR to PATTERN VECTOR
                    List)
            END IF
     END DO

1.4  DO FOR ALL (FEATUREs)
     1.4.1  IF (The number of PATTERN VECTORs in a
               FEATURE is greater than or equal to
               THRESHOLD (Pattern Vector))
            THEN
                  COMPUTE (FEATURE CENTER POSITION)
                  COMPUTE (DIAMETER (Azimuthal))
                  COMPUTE (DIAMETER (Momentum Azimuthal))
                  COMPUTE (RATIO (Momentum Diameter))
                  COMPUTE (DIAMETER (Radial))
                  COMPUTE (RATIO (Diameter))
                  IF RATIO (Momentum Diameter) is
                     greater than THRESHOLD (Minimum
                     Ratio) AND less than THRESHOLD
                     (Maximum Ratio))
                     THEN (FEATURE characterizes a
                          mesocyclone)
                     ELSE IF (RANGE (Slant) is greater than
                             or equal to THRESHOLD (Range)
                             AND RATIO (Diameter) is
                             greater than THRESHOLD
                             (Far Minimum Ratio) AND
                             less than THRESHOLD (Far
                             Maximum Ratio))
                             THEN (FEATURE characterizes
                                  a mesocyclone)
                          END IF
                  END IF
                  COMPUTE (average SHEAR (Tangential))
                  COMPUTE (HEIGHT (Feature Center))
                  COMPUTE (maximum SHEAR (Tangential))
                  COMPUTE 2-D FEATURE TYPE
                  COMPUTE (average MOMENTUM (Angular))
                  COMPUTE FEATURE EXTREMA
            END IF
     END DO
END DO
```

```
2.0  DO FOR (ELEVATIONs) FROM (Second) TO (Highest)
     2.1  DO FOR ALL (FEATUREs at the current elevation angle
                      whose HEIGHT (Feature Center) is less than
                      or equal to THRESHOLD (Feature Height))
          2.1.1  DO FOR ALL (FEATUREs at the first previous
                             elevation angle whose HEIGHT (Feature
                             Center) is less than or equal to
                             THRESHOLD (Feature Height))
                 UNTIL (a DIFFERENCE (Between Feature Centers) is
                       less than or equal to MAXIMUM FEATURE
                       DISTANCE)
                       COMPUTE (DIFFERENCE (Between Feature
                               Centers))
                       COMPUTE (MAXIMUM FEATURE DISTANCE)
                       IF (DIFFERENCE (Between Feature Centers)
                          is less than or equal to MAXIMUM
                          FEATURE DISTANCE)
                          THEN (Identify the FEATUREs as belong-
                               ing to the same vortex)
                       END IF
                 END DO

         2.1.2 IF (No DIFFERENCE (Between Feature Centers) of
                  the first previous elevation was less than
                  or equal to MAXIMUM FEATURE DISTANCE and
                  this is not the second elevation angle)
                  THEN
                  2.1.2.1 DO FOR ALL (FEATUREs at the next
                          previous elevation angle whose HEIGHT
                          (Feature Center) is less than or equal
                          to THRESHOLD (Feature Height))
                          UNTIL (a DIFFERENCE (Between
                          Feature Centers) is less than or
                          equal to MAXIMUM FEATURE DISTANCE
                          COMPUTE (DIFFERENCE (Between
                                  Feature Centers))
                          COMPUTE (MAXIMUM FEATURE DISTANCE)

                          IF (DIFFERENCE (Between Feature
                             Centers) is less than or equal
                             to MAXIMUM FEATURE DISTANCE)
                             THEN (Identify the FEATUREs
                                  as belonging to the same
                                  vortex)
                          END IF
                          END DO
                END IF
         END DO
     END DO

3.0  DO FOR ALL (ELEVATIONs)
```

```
        3.1  DO FOR ALL (FEATUREs at the current elevation
                        angle whose HEIGHT (Feature Center) is
                        less than or equal to THRESHOLD
                        (Feature Height))
             IF (FEATURE has not been identified as belonging
                to a vortex)
                THEN (identify FEATURE as belonging to a
                     vortex)
             END IF
             END DO
     END DO

4.0  DO FOR ALL (identified vortices)
        IF (Vortex has more than one FEATURE)
              THEN IF (Two or more FEATUREs characterize a meso-
                      cyclone)
                      THEN (VORTEX TYPE is mesocyclone)
                      ELSE (VORTEX TYPE is 3-D shear)
                  END IF
              ELSE (VORTEX TYPE is uncorrelated shear)
        END IF
     WRITE (VORTEX TYPE)
     WRITE (Number of FEATUREs)
     Identify FEATURE with maximum average SHEAR(Tangential)
     IF VORTEX TYPE is a mesocyclone
        THEN
        WRITE (POSITION(Mesocyclone))
        ELSE
        WRITE (FEATURE CENTER POSITION)
     END IF
     WRITE (DIAMETER(Azimuthal))
     WRITE (maximum average SHEAR(Tangential))
     WRITE (DIAMETER(Radial))
     WRITE (average MOMENTUM(Angular))
     WRITE (maximum SHEAR(Tangential))
     END DO

5.0  DO FOR ALL (mesocyclone VORTEX TYPEs)
     Assign MESOCYCLONE ID
     5.1  WRITE (MESOCYCLONE ID)
     5.2  DO FOR ALL (FEATUREs)
          5.2.1  Identify the FEATURE with the highest
                 maximum SHEAR (Tangential)
          5.2.2  COMPUTE (POSITION MAXIMUM SHEAR(Tangential))
          5.2.3  Identify the FEATURE with the lowest
                 HEIGHT (Feature Center); i.e., HEIGHT (Feature
                 Center) is the mesocyclone base.
```

```
            5.2.4  Identify the FEATURE with the highest HEIGHT
                   (Feature Center); i.e., HEIGHT (Feature Center)
                   is the mesocyclone top
            5.2.5  COMPUTE (average SPEED (Rotational))
            5.2.6  WRITE (FEATURE EXTREMA)
            END DO
       5.3  WRITE (POSITION MAXIMUM SHEAR(Tangential))
       5.4  WRITE (highest value of maximum SHEAR(Tangential))
       5.5  WRITE (lowest HEIGHT(Feature Center))
       5.6  WRITE (highest HEIGHT(Feature Center))
       5.7  WRITE (average SPEED(Rotational))
            WRITE (average SHEAR(Tangential))
       END DO

END ALGORITHM  (MESOCYCLONE DETECTION)
```

3.2 COMPUTATION

3.2.1 NOTATION

TCY = TENDENCY, the trend in Doppler velocities (increasing (+), decreasing (-)) in the azimuthal direction.

VD = VELOCITY (Doppler), the Doppler velocities in a SAMPLE VOLUME, in km/hr. Precise to .36 km/hr.

j = INDEX (Azimuth), the index for AZIMUTH.

AZIMIN = AZIMUTH MINIMUM, the smallest azimuth found within a FEATURE in radians. Precise to 1.75 x 10^{-3} radians.

AZIMAX = AZIMUTH MAXIMUM, the largest azimuth found within a FEATURE, in radians. Precise to 1.75 x 10^{-3} radians.

PI# = A mathematical constant (3.1416), unitless.

MFD = MAXIMUM FEATURE DISTANCE, a value representing the horizontal distance (formed by projecting one FEATURE diameter into the other's plane) limiting vertical correlation of two FEATUREs at consecutive elevation angles, in kilometers. Precise to 10^{-4}km.

PVE = PATTERN VECTOR, a vector which is formed when a run of increasing Doppler velocity ends. A PATTERN VECTOR contains seven components: the slant range, the azimuth angles at both ends of the run, the Doppler velocities that correspond to those azimuth angles at the slant range, and the SHEAR(Tangential) and MOMENTUM(Angular).

FEX = FEATURE EXTREMA, a set of four parameters (beginning RANGE(Slant-Feature), ending RANGE (Slant-Feature), beginning feature AZIMUTH and ending feature AZIMUTH). These are the maximum and minimum AZIMUTHs of its PATTERN VECTOR LIST, and the maximum and minimum ranges from the PATTERN VECTROR LIST.

FEA = FEATURE, a set of PATTERN VECTORs which have passed spatial proximity.

PVL = PATTERN VECTOR LIST, the set of all PATTERN VECTORs in a FEATURE.

TDFT = 2-D FEATURE TYPE, assigns an unique value to indicate that a 2-D FEATURE characterizes a MESOCYCLONE and another if it does not.

M = MOMENTUM (Angular), angular momentum, in km^2/hr. Precise to 3.6 x 10^{-5} km/hr.

Mavg = average MOMENTUM (Angular), average MOMENTUM (Angular) determined from the PATTERN VECTORs comprising a FEATURE, in km^2/hr. Precise to 3.6 x 10^{-5} km/hr.

SRT = SHEAR (Tangential), the change in Doppler velocity for a PATTERN VECTOR divided by its length, in 1/hr. Precise to 3600 1/hr.

SRTmax = maximum SHEAR (Tangential), the maximum SHEAR (Tangential) of all the PATTERN VECTORs in a FEATURE, in 1/hr. Precise to 3600 1/hr.

SRTavg = average SHEAR (Tangential), the average SHEAR (Tangential) determined from the PATTERN VECTORs comprising of a FEATURE, in 1/hr. Precise to 3600 1/hr.

SRTmaxavg= maximum average SHEAR (Tangential), the largest of all the average SHEAR (Tangentials), in 1/hr. Precise to 3600 1/hr.

VDend = ending VELOCITY (Doppler), the Doppler velocity at the end of a PATTERN VECTOR, in km/hr. Precise to .36 km/hr.

VDbeg = beginning VELOCITY (Doppler), the Doppler velocity at the beginning of a PATTERN VECTOR, in km/hr. Precise to .36 km/hr.

RS = RANGE (Slant), the slant range to the center of a SAMPLE VOLUME, in kilometers. Precise to 10^{-4} km.

AZendpv = ending pattern vector AZIMUTH, ending azimuthal position of a PATTERN VECTOR, in radians. Precise to 1.75×10^{-3} radians.

AZbegpv = beginning pattern vector AZIMUTH, ending azimuthal position of a PATTERN VECTOR, in radians. Precise to 1.75×10^{-3} radians.

FCP = FEATURE CENTER POSITION, the FEATURE center position in range, elevation and azimuth.

i = INDEX (Elevation), the index for ELEVATION.

DAA = DIAMETER (Azimuthal), azimuthal diameter of a FEATURE, in kilometers. Precise to 10^{-4} km.

MESID = MESOCYCLONE ID, an ID assigned to a mesocyclone when the MESOCYCLONE Algorithm identifies a mesocyclone.

HFClow = lowest HEIGHT(Feature Center), the lowest ELEVATION of a FEATURE center(mesocyclone base), in kilometers. Precise to 10^{-4} kilometers.

HFChigh = highest HEIGHT(Feature Center), the highest ELEVATION of a FEATURE center(mesocyclone top), in kilometers. Precise to 10^{-4} kilometers.

DMA = DIAMETER (Momentum Azimuthal), the momentum weighted azimuthal diameter of a FEATURE, in kilometers. Precise to 10^{-4} km.

DAR = DIAMETER (Radial), radial diameter of a FEATURE, in kilometers. Precise to 10^{-4} km.

ROD = RATIO (Diameter), the ratio of the azimuthal diameter to the radial diameter of a FEATURE.

RMD = RATIO (Momentum Diameter), the ratio of the momentum weighted azimuthal diameter to the radial diameter of a FEATURE.

HFC = HEIGHT(Feature Center), the ELEVATION of a FEATURE center, in kilometers. Precise to 10^{-4}km.

PHI# = ELEVATION, elevation angle, in radians. Precise to 1.75 x 10^{-3} radians.

RE = RADIUS (Earth), radius of the Earth (6371), in kilometers. Precise to 10^{-4} km.

RSFEbeg = Beginning RANGE (Slant-Feature), the beginning slant range of a FEATURE, in kilometers. Precise to 10^{-4} km.

RSPV = RANGE(Slant Pattern Vector), the RANGE(Slant) of a PATTERN VECTOR, in kilometers. Precise to 10^{-4} km.

RSFEcen = Center RANGE(Slant-Feature), the slant range of a FEATURE center, in kilometers. Precise to 10^{-4} km.

RSFEend = Ending RANGE (Slant-Feature), the ending slant range of a FEATURE, in kilometers. Precise to 10^{-4} km.

DIF = DIFFERENCE (Between Feature Centers), the horizontal distance between FEATURE CENTER POSITIONs (at adjacent elevation angles), in kilometers. Precise to 10^{-4} km.

VTY = VORTEX TYPE, designates whether vorticies composed of one or more FEATUREs represent a mesocyclone, 3-D shear, or uncorrelated shear, unitless.

YFCP = Y-POSITION(Feature Center), Y-position of the FEATURE CENTER after conversion from polar to Cartesian coordinates, in kilometers. Precise to 10^{-4} kilometers.

XFCP = X-POSITION(Feature Center), X-position of the FEATURE CENTER after conversion from polar to Cartesian coordinates, in kilometers. Precise to 10^{-4} kilometers.

PM = POSITION (Mesocyclone), the mesocyclone position in range, azimuth and elevation angle, in kilometers, radians and radians. Precise to 10^{-4} kilometers, 1.75 x 10^{-3} radians.

SPRavg = average SPEED(Rotational), half the momentum weighted diameter of a FEATURE times the average SHEAR(Tangential), in km/hr. Precise to .36 km/hr.

AZcenfe = AZIMUTH(Center Feature), the center azimuth of a 2-dimensional FEATURE, momentum weighted, in radians. Precise to 1.75×10^{-3} radians.

PMST = POSITION MAXIMUM SHEAR(Tangential), the RANGE (Slant), beginning pattern vector AZIMUTH and ending pattern vector AZIMUTH where the maximum SHEAR(Tangential) is found in a feature classified as a mesocyclone vortex, in kilometers, radians and radians. Precise to 10^{-4} kilometers, 1.75×10^{-3} radians.

Note: Precision is equivalent to the units unless otherwise stated.

3.2.2 SYMBOLIC FORMULAS

COMPUTE (TENDENCY)

$TCY = \text{Sign of } VD_j - VD_{j-1}, \text{ or } 0$

COMPUTE (MOMENTUM (Angular))

$M = ABS\,[(VDend - VDbeg)(RS)\ (AZend - AZbeg)]$

COMPUTE (SHEAR (Tangential))

$SRT = ABS\,[(VDend - VDbeg)/(RS)(AZendpv - AZbegpv)]$

COMPUTE average (MOMENTUM (Angular))

$$Mavg = \sum_n ABS\left[\frac{(VDend_n - VDbeg_n)(RSPV)(AZend_n - AZbeg_n)}{n}\right]$$

COMPUTE (FEATURE CENTER POSITION)

$FCP_i\,(AZcenfe, RSFEcen)$

where,

$$AZcenfe = \sum_n \Big[[AZbegpv_n + (DAZ_n/2)](VM_n)\Big] \Big/ \sum_n VM_n$$

where, $DAZ_n = ABS(AZbegpv_n - AZendpv_n)$

and $VM_n = ABS[(DAZ_n)(VDendpv_n - VDbegpv_n)]$

NOTE: Corrections for crossing 360° or counterclockwise rotation are not accounted for here.

$$RSFEcen = \Big[\sum_n \{ABS[(VDend_n - VDbeg_n)(AZendpv_n - AZbegpv_n)(RSPV_n)]\}\Big] \Big/ \Big[\sum_n \{ABS[(VDend_n - VDbeg_n)(AZendpv_n - AZbegpv_n)]\}\Big]$$

and n is the PATTERN VECTOR number.

COMPUTE (DIAMETER (Azimuthal))

$$\mathrm{DAA} = \left[\sum_n \{[(\mathrm{AZendpv}_n - \mathrm{AZbegpv}_n)^2]\}(\mathrm{RSFEcen})\right] / \left[\sum_n \{\mathrm{ABS}(\mathrm{AZendpv}_n - \mathrm{AZbegpv}_n)\}(\pi/4)\right]$$

and n is the PATTERN VECTOR number.

COMPUTE (DIAMETER (Momentum Azimuthal))

$$\mathrm{DMA} = (3\pi/8)\left[\sum_n \{\mathrm{ABS}[(\mathrm{AZendpv}_n - \mathrm{AZbegpv}_n)^2 (\mathrm{VDend}_n - \mathrm{VDbeg}_n)]\}(\mathrm{RSFEcen})\right] / \left[\sum_n \{\mathrm{ABS}[(\mathrm{VDend}_n - \mathrm{VDbeg}_n)(\mathrm{AZendpv}_n - \mathrm{AZbegpv}_n)]\}\right]$$

where n is the PATTERN VECTOR number.

COMPUTE (DIAMETER (Radial))

$\mathrm{DAR} = \mathrm{RSFEend} - \mathrm{RSFEbeg}$

COMPUTE (RATIO (Diameter))

$\mathrm{ROD} = \mathrm{DAA}/\mathrm{DAR}$

COMPUTE (RATIO (Momentum Diameter))

$\mathrm{RMD} = \mathrm{DMA}/\mathrm{DAR}$

COMPUTE (HEIGHT(Feature Center))

$$\mathrm{HFC} = [\mathrm{RSFEcen}(\sin \phi)] + [(\mathrm{RSFEcen})(\cos \phi)]^2/[(2.21)(\mathrm{RE})]$$

COMPUTE (maximum SHEAR (Tangential))

$\mathrm{SRTmax} = \mathrm{SRT}$ if $\mathrm{SRT} \geq \mathrm{SRTmax}$

where;

$$\mathrm{SRT} = \mathrm{ABS}\ [(\mathrm{VDend} - \mathrm{VDbeg})/[(\mathrm{RS})\ (\mathrm{AZendpv} - \mathrm{AZbegpv})]]$$

COMPUTE (average SHEAR (Tangential))

$$\mathrm{SRTavg} = \frac{\sum_n \mathrm{ABS}[(\mathrm{VDend}_n - \mathrm{VDbeg}_n)/(\mathrm{RSPV}_n)(\mathrm{AZendpv}_n - \mathrm{AZbegpv}_n)]}{n}$$

where n is the PATTERN VECTOR number.

COMPUTE (DIFFERENCE (Between Feature Centers))

$$DIF = \{[XFCP_i - XFCP_{i-1}]^2 + [YFCP_i - YFCP_{i-1}]^2\}^{1/2}$$

where,

$XFCP = RSFEcen[\cos(AZcenfe)]$

$YFCP = RSFEcen[\sin(AZcenfe)]$

COMPUTE (MAXIMUM FEATURE DISTANCE)

$$MFD = \{[(DAA_i + DAR_i)/2] + [(DAA_{i-1} + DAR_{i-1})/2]\}/2$$

where i is the current elevation angle of the vertical correlation.

COMPUTE (POSITION MAXIMUM SHEAR(Tangential))

This includes the RANGE(Slant), beginning pattern vector AZIMUTH and ending vector AZIMUTH of the pattern vector containing the maximum SHEAR(Tangential).

COMPUTE (average SPEED (Rotational))

$SPRavg = SRTavg\ (DMA/2)$

COMPUTE (2-D Feature Type)

Assign an unique value to indicate that a 2-D FEATURE characterizes a mesocyclone and another if it does not.

COMPUTE (FEATURE EXTREMA)

A set of four parameters. Determine the maximum and minimum AZIMUTHs in the PATTERN VECTOR LIST, and the maximum and minimum ranges in the PATTERN VECTOR LIST.

Note: These may belong to separate PATTERN VECTORs.

4.0 OUTPUTS

4.1 IDENTIFICATION

For each vortex found by this algorithm, the following are also outputted:

- VORTEX TYPE
- number of FEATUREs in vortex

For the FEATURE with the maximum SHEAR(Tangential), the following is outputted:

- DIAMETER(Azimuthal)
- DIAMETER(Radial)
- HEIGHT(Feature Center)
- average MOMENTUM(Angular)
- FEATURE CENTER POSITION
- a value for maximum SHEAR(Tangential)

For each vortex classified as a MESOCYCLONE ID, these additional values are outputted:

- Mesocyclone top value (highest HEIGHT (Feature Center))
- Mesocyclone base value (lowest HEIGHT (Feature Center))
- Mesocyclone position (POSITION(Mesocyclone))
- average SPEED(Rotational)
- FEATURE EXTREMA for each FEATURE in MESOCYCLONE ID
- average SHEAR(Tangential)

4.2 DISTRIBUTION

Output from the MESOCYCLONE DETECTION algorithm can be used as input to a mesocyclone tracking algorithm and a mesocyclone forecast algorithm. The output can also be used for severe weather warning procedures. FEATURE EXTREMA, FEATURE and MESOCYCLONE ID are input to the TVS (026) algorithm.

5.0 INFERENCES

5.1 LIMITATIONS

The MESOCYCLONE DETECTION algorithm does not consider meso-anticyclones. Before a FEATURE can be classified as a mesocyclone, time continuity must be established. The successful detection of mesocyclones by the MESOCYCLONE DETECTION algorithm depends upon the selection of optimum high and low shear thresholds and high and low momentum thresholds, and upon the distance threshold for vertical correlation. Also, bad data can artificially end a pattern vector.

5.2 FUTURE DEVELOPEMENTS

The MESOCYCLONE DETECTION algorithm remains under development. Optimum high and low momentum thresholds, high and low shear thresholds, as well as more refined range dependent symmetry criteria, will be determined. The results of algorithm testing may affect the values assigned to other constants.

STORM TRACKING

ALGORITHM DESCRIPTION

NX-DR-03-004/26

MAJOR REVISIONS SINCE MAY 1984

Storm Tracking (004)

1. All algorithms appearing in the May 1984 report have undergone the following changes:

   a. Editorial and typographical changes.

   b. Explicit declaration of data element precision.

   c. Renaming of data element names and symbols to achieve unique naming.

   d. Data Dictionary changes resulting from other changes.

2. Two changes have been made to improve tracking consistency. Formerly, a 360 degree search was done. Now the search is narrowed based on an adaptable parameter and past speed. Also, a gross mass check is done to prevent cross over of storm tracks between large and small cells.

3. Specific information on the contents of CORRELATION (Table) has been provided.

4. The following inputs were added: SPEED (MEAN), DIRECTION (MEAN) and MASS (STORM).

1.0 PROLOGUE

1.1 FUNCTIONAL DESCRIPTION

The STORM TRACKING algorithm is used to monitor the movement of isolated storms by relating all storms found in the current volume scan to the storms from the previous volume scan. The storms are related to each other, in time and space, through the use of a correlation table. If a storm cannot be related to a storm from the previous scan, it will be added to the list of storms already identified and be designated as being new.

The storms are related as follows. The centroid position of the most intense (largest mass weighted volume) storm at the current time is compared to the centroid positions of storms from the previous time, starting with the most intense to the least intense storm. The storm from the previous time, with a centroid located within a calculated direction and distance from the current storm is correlated, i.e., considered the same storm. The centroid positions used are in a Cartesian coordinate system with the radar at the origin, and where the X-axis denotes east-west directions, the Y-axis denotes north-south directions, and the Z-axis denotes heights above the radar.

1.2 SOURCE

The STORM TRACKING algorithm described herein has been implemented by Air Force personnel at the Air Force Geophysics Laboratory (AFGL) in Sudbury, Massachusetts.

REFERENCES

Bjerkaas, C.L., and D.E. Forsyth, 1980: An Automated Real-Time Storm Analysis and Storm Tracking Program (WEATRK). AFGL-T-80-0316, Air Force Geoophysics Laboratory, Hanscom AFB, Massachusetts 01731.

1.3 PROCESSING ENVIRONMENT

The STORM TRACKING algorithm is one part of the total storm movement prediction process. This algorithm needs data from a storm isolation process giving locations of identified storms over a known period of time. Therefore, the correlation table must be updated after each algorithm pass. An algorithm for such a process is described in the STORM CENTROIDS [005] algorithm description. To complete the prediction process, the STORM POSITION FORECAST [008] algorithm must be used.

2.0 INPUTS

2.1 IDENTIFICATION

CORRELATION (Speed) = Speed used to compute the CORRELATION (Distance), in km/hr.

CORRELATION (Table) = A data set used to keep track of the positions of correlated STORMS.

STORM = A three-dimensional region composed of STORM COMPONENTs characterized by reflectivity values above a given threshold, ordered by mass weighted volume.

MASS(Storm) = The mass weighted volume of a STORM in kilomgrams. Precise to 10^{-3} kilograms.

SPEED(Mean) = The SPEED(Storm) either obtained from VAD algorithm, average of SPEED(Storm) or operator input, in km/hr.

SPEED(Minimum) = The minimum SPEED a STORM must have in order for a 360 degree search to be conducted to find its next position (for STORMs moving faster than this SPEED, a smaller search window is used) (2), in km/hr.

DIRECTION(Mean) = The direction from which a STORM is moving. This is either obtained from the VAD algorithm, the average of the DIRECTION (Storm) or operator input. in radians.

TIME (Scan) = The beginning time of a scan, in hours. Precise to 1/3600 hr.

X-POSITION (Centroid) = X-position of a STORM CENTROID (center of mass), in kilometers. Precise to 10^{-4} kilometers.

Y-POSITION (Centroid) = Y-position of a STORM CENTROID (center of mass), in kilometers. Precise to 10^{-4} kilometers.

2.2 ACQUISITION

CORRELATION (Speed) is a constant based on empirical and theoretical studies of storm movements.

CORRELATION (Table) is an internal table used to keep track of the positions of correlated STORMs.

Time (Scan) is acquired by means of direct measurements conducted at the beginning of volume scans of the radar.

STORMs, X-POSITION (Centroid), MASS(Storm), SPEED(Storm), SPEED (Minimum), DIRECTION(Mean), and Y-POSITION (Centroid) are acquired after the STORMs are isolated based on reflectivity data obtained by a weather radar. The details of isolating storms are described under a separate algorithm description called STORM CENTROIDS [005].

3.0 PROCEDURE

3.1 ALGORITHM

```
BEGIN ALGORITHM (STORM TRACKING)

1.0  COMPUTE (TIME (Scan) difference)

2.0  COMPUTE (CORRELATION (Distance))

3.0  DO FOR ALL (STORMs at the previous time)
     3.1  IF (SPEED (Storm) nonexistent)
             THEN (Use SPEED (Mean) and DIRECTION (Mean))
             END IF
     3.2  IF (SPEED (Storm) greater than SPEED (Minimum))
             THEN
                 COMPUTE (BEST X-Position)
                 COMPUTE (BEST Y-Position)
                 COMPUTE (DIRECTION (Minus))
                 COMPUTE (DIRECTION (Plus))
          END IF
         END DO

4.0  DO FOR ALL (STORMs at the current time)
     4.1  DO FOR ALL (STORMs from the previous time)
          4.1.1 COMPUTE (X-POSITION (Centroid) difference)
          4.1.2 COMPUTE (Y-POSITION (Centroid) difference)
          4.1.3 COMPUTE (DIRECTION (Storm Position))
          4.1.4 IF (X-POSITION (Centroid) difference AND
                   Y-POSITION (Centroid) difference are less than
                   than CORRELATION (Distance) AND (STORM from
                   previous time has not already been correlated)
                   THEN
                    IF (BEST X-POSITION and BEST Y-POSITION
                       exist)
                              THEN
                           IF (DIRECTION (Storm Position) greater
                              than or equal to DIRECTION (Minus)
                              AND DIRECTION (Storm Position) less
                              than or equal to DIRECTION (Plus))
                              THEN
                                 COMPUTE (MASS-VOLUME RATIO)
                                 IF (MASS-VOLUME RATIO less than
                                    RATIO(Minimum))
                                    THEN
                                      COMPUTE (DIFFERENCE (Best
                                              Position))
                                      IF (Smallest DIFFERENCE
                                         (Best Position))
                                         THEN (Identify as same
                                              STORM from previous
                                              TIME in CORRELATION
                                              (Table))
                                    END IF
                                END IF
                                ELSE (Correlation not made)
                           END IF
                       ELSE (Identify as same STORM from previous
                            TIME in CORRELATION (Table))
                   END IF
               END IF
           END DO
       END DO

5.0 WRITE (CORRELATION (Table))

END ALGORITHM (STORM TRACKING)
```

3.2 COMPUTATION

3.2.1 NOTATION

TSdif = TIME (Scan) difference, time difference between scans, in hours. Precise to 1/3600 hr.

TScur = TIME (Scan) current, the current time at which data is collected, in hours. Precise to 1/3600 hr.

TSpre = TIME (Scan) previous, the previous time at which data was collected, in hours. Precise to 1/3600 hr.

CD = CORRELATION (Distance), defines the distance used between centroids) to determine if a current storm is the same as one of the storms identified earlier, in kilometers. Precise to 10^{-4} kilometers.

CS = CORRELATION (Speed), the speed used to compute the CORRELATION (Distance), in km/hr. Precise to .36 km/hr.

XCdif = X-POSITION (Centroid) difference, the difference between X-POSITION (Centroid) of a storm at the current time and X-POSITION (Centroid) of a storm at the previous time.

BXP = BEST X-POSITION, an X-position based on either the SPEED (Mean) or previous SPEED (Storm), in kilometers. Precise to 10^{-4} kilometers.

BYP = BEST Y-POSITION, a Y-position based on either the SPEED (Mean) or previous SPEED (Storm), in kilometers. Precise to 10^{-4} kilometers.

BXS = BEST X-SPEED, the SPEED in the X-direction, in km/hr. Precise to .36 km/hr.

BYS = BEST Y-SPEED, the SPEED in the Y-direction, in km/hr. Precise to .36 km/hr.

SPM = SPEED (Mean), the SPEED (Storm) either obtained from the average of SPEED (Storm) or operator input, in km/hr. If neither is available, a default value of 0 will be used. Precise to .36 km/hr.

DMN = DIRECTION (Mean), the direction from which a STORM is moving. This is either obtained from the VAD algorithm, the average of the DIRECTION (Storm) or the operator input, in radians. Precise to 10^{-3} radians.

DBP = DIRECTION (Best Position), the direction towards which a STORM is moving, in radians. Precise to 10^{-3} radians.

DM = DIRECTION (Minus), the DIRECTION (Best Position) minus the DIRECTION (Limit), in radians. Precise to 10^{-3} radians.

DP = DIRECTION (Plus), the DIRECTION (Best Position) minus the DIRECTION (Limit), in radians. Precise to 10^{-3} radians.

DLM = DIRECTION (Limit), the maximum deviation from the DIRECTION (Best Position) that a STORM is allowed in order to be considered as the same STORM at a previous time (PI#/2), in radians. Precise to 10^{-3} radians.

DSP = DIRECTION (Storm Position), the direction between centroids at the current time and centroids at the previous time, in radians. Precise to 10^{-3} radians.

MVR = MASS-VOLUME RATIO, the ratio of the STORM's mass volume at the current time, to the STORM's mass volume at the previous time. The value is always 1 or greater.

MSTcur = current MASS (Storm), the mass weighted volume of a STORM at the current time, in kilograms. Precise to 10^{-3} kilograms.

RATM = RATIO(Minimum), the minimum MASS-VOLUME RATIO needed before the distance correlation will be made. This is a site-adaptable parameter with the current implemented NSSL value being 10.

SPDM = SPEED(Minimum), the minimum SPEED a STORM must have in order for a 360 degree search to be conducted to find its next position (for STORMs moving faster than this SPEED, a smaller search window is used) (2), in km/hr. Precise to .36 km/hr.

MSTpre = previous MASS (Storm), the mass weighted volume of a STORM at the previous time, in kilograms. Precise to 10^{-3} kilograms.

BPD = DIFFERENCE (Best Position), the distance between the best position point as computed by the SPEED (Mean) and direction or STORM (Speed) and direction and the current position of the STORM CENTROID, in kilometers. Precise to 10^{-4} kilometers.

XCpre = Previous X-POSITION (Centroid), X-position of a STORM CENTROID (center of mass), at a previous time, in kilometers. Precise to 10^{-4} kilometers.

XCcur = Current X-POSITION (Centroid), X-position of a STORM CENTROID (center of mass), at the current time in kilometers. Precise to 10^{-4} kilometers.

YCdif = difference Y-POSITION (Centroid), the difference between Y-POSITION (Centroid) of a storm at the current time and Y-POSITION (Centroid) of a storm at the previous time.

YCpre = Previous Y-POSITION (Centroid), Y-position of a STORM CENTROID (center of mass), at the previous time, in kilometers. Precise to 10^{-4} kilometers.

YCcur = Current Y-POSITION (Centroid), Y-position of a STORM CENTROID (center of mass), at the current time, in kilometers. Precise to 10^{-4} kilometers.

Note: This algorithm was implemented using 32 bit precision at AFGL.

Note: Precision is to the units unless otherwise specified.

3.2.2 SYMBOLIC FORMULAS

COMPUTE (TIME (Scan) difference)

$TSdif = (TScur - TSpre)$

COMPUTE (CORRELATION (Distance))

$CD = (TSdif)(CS)$

COMPUTE (X-POSITION (Centroid) difference)

$XCdif = |XCpre - XCcur|$

COMPUTE (Y-POSITION (Centroid) difference)

$YCdif = |YCpre - YCcur|$

COMPUTE (BEST X-POSITION)

$BXP = XCpre + (BXS)(TSdif)$

where BXS is either computed from the DIRECTION (Mean) and SPEED(Mean) or obtained from previous SPEED(Storm) and DIRECTION(Storm). For DIRECTION (Mean) and SPEED (Mean):

$BXS = (SPM) \sin (DBP)$

where $DBP = DMN - 180^{\circ}$

IF (DBP.LT.0), $DBP = DBP + 360^{\circ}$

COMPUTE (BEST Y-POSITION)

$BYP = YCpre + (BYS)(TSdif)$

where BYS is either computed from the DIRECTION (Mean) and SPEED(Mean) or obtained from previous SPEED(Storm) and DIRECTION(Storm). For DIRECTION (Mean) and SPEED (Mean):

$BYS = (SPM) \cos (DBP)$

where $DBP = DMN - 180^{\circ}$

IF (DBP.LT.0) $DBP = DBP + 360^{\circ}$

COMPUTE (DIRECTION (Minus))

$DM = DBP - DLM$

where DBP is calculated as in BEST X-POSITION using either previous DIRECTION (Storm) or DIRECTION (Mean).

COMPUTE (DIRECTION (Plus))

$DP = DBP + DLM$

COMPUTE (DIRECTION (Storm Position))

$DSP = \tan^{-1}[(XCcur - XCpre)/(YCcur - YCpre)]$

COMPUTE (MASS - VOLUME RATIO)

$$MVR = \frac{MSTcur}{MSTpre}$$

COMPUTE (DIFFERENCE (Best Position))

$BPD = [(BPDX)(BPDX) + (BPDY)(BPDY)]^{1/2}$

where

$BPDX = | XCcur - BXP|$

and

$BPDY = | YCcur - BYP|$

4.0 OUTPUTS

4.1 IDENTIFICATION

CORRELATION (Table) is a data set used to keep track of the positions of correlated STORMs. It consists of a list of indices which allow the meteorologist to identify and track the same STORM through a series of 12 separate time steps.

For example, during the 1st time step, a STORM is identified and is given an index according to its mass. During subsequent time steps, other STORMs are identified and ranked by index. The CORRELATION(Table) cross references these newly defined STORMs with those tracked from the previous time steps. By continuing this process, the same STORM can be tracked through all 12 time steps.

4.2 DISTRIBUTION

The output of this algorithm is for use by the STORM POSITION FORECAST [008] algorithm. Since the output is intermediate and specific, it may not be distributed for use by other weather analysis algorithms. However, the table could be used by a post-processing algorithm to display the storm movement over a period of time.

5.0 INFERENCES

5.1 LIMITATIONS

This algorithm's effectiveness could be limited by very erratic storm motion. If storms cross paths, or are in close proximity and their intensities switch, the wrong storm could be identified. Although this is unlikely, the actual frequency of such an occurrence is unknown. Moreover, if the storms moved faster than the CORRELATION (SPEED) or the TIME (Scan) difference was too large, problems in identification could occur.

STORM CENTROIDS

ALGORITHM DESCRIPTION

NX-DR-03-005/45

MAJOR REVISIONS SINCE MAY 1984

Storm Centroids (005)

1. All algorithms appearing in the May 1984 report have undergone the following changes:

    a. Editorial and typographical changes.

    b. Explicit declaration of data element precision.

    c. Renaming of data element names and symbols to achieve unique naming.

    d. Data Dictionary changes resulting from other changes.

2. The ADJACENCY formula has been changed to reflect the fact that delta azimuth may not equal BEAM WIDTH. Consequently, references to BEAM WIDTH have been removed from the algorithm.

3. SHAPE computations have been added to improve cell isolation in height.

4. The following WRITE statements were added: MASS (Storm Component), MASS (Storm), HEIGHT (Storm) and HEIGHT (Storm Component-Centroid).

1.0 PROLOGUE

1.1 FUNCTIONAL DESCRIPTION

The purpose of this algorithm is to determine the centroids of storms. The contiguous significant reflectivity (≥ 30 dBZe) values collected along the radials (identified as segments) of a volume scan are used to determine the location of the centroids, or centers of mass, of storms. The determination of the centroid is carried out in two steps. In step one, regions of significant reflectivity at known elevation angles are determined by finding contiguous segments as a function of azimuth. These regions are defined as storm components (see Figure 1). The azimuthal spacing between radials is expected to be approximately equal to the radar beam width so that no gaps exist between segments. A 2D center of mass is computed for each identified storm component in a rectangular coordinate system with the radar at the origin, and where the X-axis denotes east-west directions and the Y-axis denotes north-south directions. In step two, storm components at different elevation angles are correlated vertically along the Z-axis denoting heights above the radar at corresponding elevations. Vertical correlation means finding those storm components at different elevation angles whose centers of mass are closest in proximity with respect to the X-Y plane. The vertically correlated storm components constitute a single storm, referred to as an unordered storm, and the effective center of mass of the storm is computed. These unordered storms are then ranked in the order of their mass weighted volumes. After the unordered storms are ranked they are referred to as "storms". The 3D centers of mass are then projected onto the X-Y plane denoting the center of mass, or centroid, of each storm.

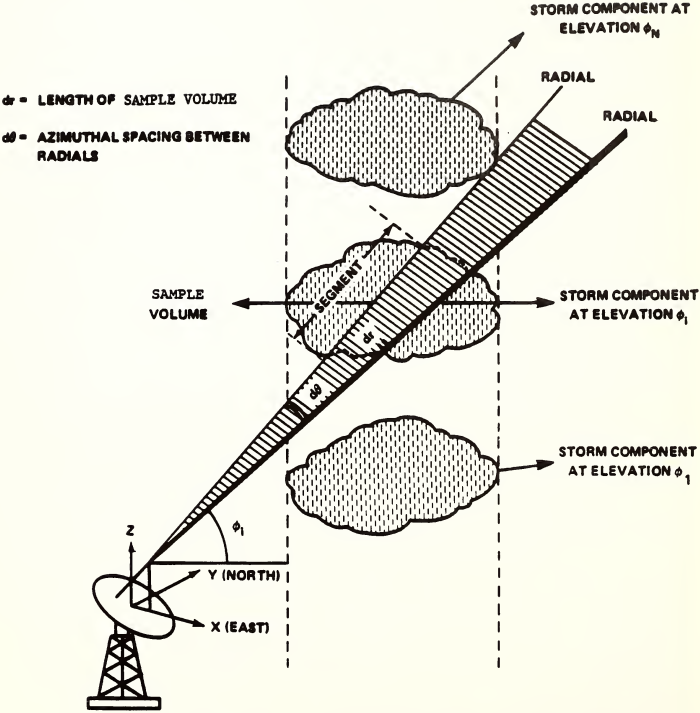
1.2 SOURCE

This algorithm has been implemented at the Air Force Geophysics Laboratory (AFGL), Sudbury, Massachusetts. Originally developed by Raytheon Corporation (AFGL-TR-77-0259) as a 2D system, D. Forsyth and C. Bjerkaas modified it to a 3D system at AFGL.

REFERENCES

Bjerkaas, C.L., and D.E. Forsyth, 1980: An Automated Real-Time Storm Analysis and Storm Tracking Program (WEATRK). AFGL-TR-80-0316, Air Force Geophysics Laboratory, Hanscom AFB, Massachusetts 01731.

Boak, III, T.I.S., A.J. Jagodnik, Jr., R.B. Marshall, D. Riceman, and M.J. Young, 1977: R & D Equipment Report - Tracking and Significance Estimator. AFGL-TR-77-0259, Air Force Geophysics Laboratory, Hanscom AFB, Massachusetts 01731.



STORM COMPONENT AT ELEVATION ϕ_N
RADIAL
RADIAL
dr = LENGTH OF SAMPLE VOLUME
dθ = AZIMUTHAL SPACING BETWEEN RADIALS
SEGMENT
SAMPLE VOLUME
STORM COMPONENT AT ELEVATION ϕ_i
dr
dθ
STORM COMPONENT AT ELEVATION ϕ_1
ϕ_i
Z
Y (NORTH)
X (EAST)

FIGURE 1. 3D STORM

1.3 PROCESSING ENVIRONMENT

The STORM CENTROIDS algorithm produces output which are inputs to the STORM TRACKING [004] algorithm and the data elements included in this description are only those relevant to the storm tracking. This algorithm requires outputs from the STORM SEGMENTS [022] algorithm.

2.0 INPUTS

2.1 IDENTIFICATION

AZIMUTH = Azimuthal position, in radians.

ELEVATION = Elevation angle, in radians.

MASS WEIGHTED LENGTH = Mass density weighted length of a STORM SEGMENT, in kg/km^2.

MASS WEIGHTED LENGTH SQUARED = Mass density weighted length squared of a STORM SEGMENT, in kg/km.

RADIUS CORRECTION (Earth) = The factor by which the RADIUS (Earth) is multiplied to account for refraction of the radar beam (1.21).

RANGE SAMPLE SPACING = The difference in ranges between two adjacent SAMPLE VOLUMEs along a radial, i.e., the length of a SAMPLE VOLUME (1), in kilometers.

REFLECTIVITY FACTOR (DBZE) = The effective radar reflectivity factor factor of a SAMPLE VOLUME, in dBZe.

SPECTRUM WIDTH = Spectrum width value, in km/hr.

STORM SEGMENT = A set of numbered, contiguous SAMPLE VOLUMEs along a radial identified by reflectivity factor values above a specified threshold. A STORM SEGMENT includes: beginning RANGE(Slant), ending RANGE(Slant), maximum REFLECTIVITY FACTOR(DBZE), most minimum and most maximum VELOCITY(Doppler), maximum SPECTRUM WIDTH, AZIMUTH and ELEVATION angle.

THRESHOLD (Overlap) = Minimum number of SAMPLE VOLUMEs (assuming 1 km RANGE SAMPLE SPACING) that must overlap in range in order for adjacent azimuths to be identified as part of the same STORM COMPONENTs.

THRESHOLD (Segment Length) = The minimum length of a STORM SEGMENT (4.2), in kilometers.

VELOCITY (Doppler) = Doppler velocities in a data SAMPLE VOLUME, in km/hr.

2.2 ACQUISITION

AZIMUTH and ELEVATION are acquired as measured data from the radar's instantaneous position during radial data collection.

THRESHOLD (Overlap) and THRESHOLD (Segment Length) are supplied as parameters whose values are based on empirical and theoretical studies of storms, and are site-adaptable parameters.

MASS WEIGHTED LENGTH, MASS WEIGHTED LENGTH SQUARED, REFLECTIVITY FACTOR (DBZE), VELOCITY (Doppler) and SPECTRUM WIDTH are acquired from the STORM SEGMENTS [022] algorithm.

RANGE SAMPLE SPACING is a NEXRAD system radar parameter. STORM SEGMENTs are the outputs produced by the STORM SEGMENTS [022] algorithm.

RADIUS CORRECTION (Earth) is supplied as a parameter whose value is based on scientific/theoretical studies.

3.0 PROCEDURE

3.1 ALGORITHM

```
BEGIN ALGORITHM (STORM CENTROIDS)

1.0  DO FOR ALL (ELEVATIONs)
     1.1  DO FOR ALL (Pairs of adjacent AZIMUTHs)
          1.1.1  DO FOR ALL (Adjacent pairs of STORM SEGMENTs)
                 1.1.1.1  Look for overlapping sample
                          volumes among a pair of contiguous
                          STORM SEGMENTs indicated by
                          identical sample volume
                          numbers.
                 1.1.1.2  IF (The length of overlap between
                             STORM SEGMENTs is greater than
                             or equal to THRESHOLD (Overlap))
                             THEN (Identify STORM SEGMENT as
                                  part of the same POSSIBLE
                                  COMPONENT)
                          END IF
                 END DO
          END DO
     1.2  DO FOR ALL (POSSIBLE COMPONENTs)
          1.2.1  Count the number of AZIMUTHs in current
                 STORM COMPONENT.
          1.2.2  COMPUTE (ADJACENCY)
                 COMPUTE (begin AZIMUTH RANGE (SLANT))
                 COMPUTE (end AZIMUTH RANGE (SLANT))
          1.2.3  IF (Number of AZIMUTHs is equal to or greater
                    than ADJACENCY)
                    THEN (Identify POSSIBLE COMPONENT as STORM
                         COMPONENT)
                         COMPUTE (MASS (Storm Component))
                         COMPUTE (X-POSITION)
                         COMPUTE (Y-POSITION)
                         COMPUTE (AREA (Storm Component))
                         COMPUTE (CENTROID DISTANCE)
                         COMPUTE (SHAPE (Length))
                         COMPUTE (SHAPE (AXIS2))
                         COMPUTE (SHAPE (Orientation))
                         COMPUTE (SHAPE (Ellipticity))
                         WRITE (CENTROID DISTANCE)
                         WRITE (X-POSITION)
                         WRITE (Y-POSITION)
                         WRITE (AREA (Storm Component))
                         WRITE (MASS (Storm Component))
                 END IF
          END DO
     END DO
```

```
2.0  DO FOR ALL (Second ELEVATION to highest ELEVATION)
     2.1  DO FOR ALL (STORM COMPONENTs at current elevation)
             DO FOR ALL (STORM COMPONENTs at previous elevation)
                 COMPUTE (MAXIMUM CENTROID DISTANCE)
                 COMPUTE (first X-POSITION difference)
                 COMPUTE (first Y-POSITION difference)
                 IF (first X-POSITION difference AND first
                    Y-POSITION difference are less than or
                    equal to MAXIMUM CENTROID DISTANCE)
                        THEN (Identify as an unordered STORM)
                 END IF
             END DO
                 IF (STORM not identified as unordered STORM)
                    THEN
                       DO FOR ALL (STORM COMPONENTs at the
                                   second previous elevation)
                          COMPUTE (MAXIMUM CENTROID DISTANCE)
                          COMPUTE (second X-POSITION difference)
                          COMPUTE (second Y-POSITION difference)
                          IF (second X-POSITION difference
                             AND second Y-POSITION difference
                             are less than MAXIMUM CENTROID
                             DISTANCE)
                             THEN (Identify as unordered STORM)
                          END IF
                       END DO
                 END IF
          END DO
     END DO

3.0  DO FOR ALL (unordered STORMs)
     3.1  COMPUTE (MASS (Storm))
     3.2  COMPUTE (X-POSITION(Centroid))
     3.3  COMPUTE (Y-POSITION(Centroid))
     3.4  COMPUTE (HEIGHT(Storm))
     END DO

4.0  DO FOR ALL (unordered STORMs)
     4.1  Select the next storm with greatest MASS (Storm)
          not previously detected.
     4.2  WRITE (STORMs)
     4.3  WRITE (X-POSITION)
     4.4  WRITE (Y-POSITION)
     4.5  WRITE (MASS (Storm))
     4.6  WRITE (HEIGHT (Storm))
     END DO
```

```
5.0  DO FOR ALL (ELEVATIONs)
     5.1  DO FOR ALL (STORM COMPONENTs)
          5.1.1  COMPUTE (HEIGHT (Storm Component-Centroid))
          5.1.2  COMPUTE (maximum REFLECTIVITY FACTOR
                         (DBZE))
          5.1.3  COMPUTE (maximum VELOCITY (Doppler))
          5.1.4  COMPUTE (maximum SPECTRUM WIDTH)
          5.1.5  WRITE (maximum REFLECTIVITY FACTOR
                       (DBZE))
          5.1.6  WRITE (maximum VELOCITY (Doppler))
          5.1.7  WRITE (maximum SPECTRUM WIDTH)
          5.1.8  WRITE (HEIGHT (Storm Component-Centroid))
          END DO
     END DO

END ALGORITHM (STORM CENTROIDS)
```

3.2 COMPUTATION

3.2.1 NOTATION

ADJ = ADJACENCY, the number of adjacent azimuths required to define a STORM COMPONENT.

TSL = THRESHOLD (Segment Length), the minimum length of a STORM SEGMENT (4.2), in kilometers. Precise to 10^{-4} kilometers.

RSSSbeg = beginning RANGE (Slant-Storm Segment), the beginning slant range (center of SAMPLE VOLUME) of a STORM SEGMENT, in kilometers. Precise to 10^{-4} kilometers.

ADJmin = ADJACENCY (Minimum), the minimum number of adjacent azimuths required to define a STORM COMPONENT(1).

HSTO = HEIGHT(Storm), the height of a STORM CENTROID (center of mass), in kilometers. Precise to 10^{-4} kilometers.

RSSS = RANGE(Slant-Storm Segment), the slant range (center of SAMPLE VOLUME) of a STORM SEGMENT, in kilometers. Precise to 10^{-4} kilometers.

RSSSend = ending RANGE (Slant Storm Segment), the ending slant range (center of SAMPLE VOLUME) of a STORM SEGMENT, in kilometers. Precise to 10^{-4} kilometers.

RSS = RANGE SAMPLE SPACING, the difference in ranges between two adjacent SAMPLE VOLUMEs along a radial, i.e., the length of a SAMPLE VOLUME (1), in kilometers. Precise to 10^{-4} kilometers.

AZDE = Azimuth (Delta), the azimuthal increment, in radians. Precise to 10^{-3} radians.

ARSbeg = Beginning AZIMUTH RANGE (Slant), the average slant range for the first azimuth of a STORM COMPONENT, in kilometers. Precise to 10^{-4} kilometers.

ARSend = Ending AZIMUTH RANGE (Slant), the average slant range for the last azimuth of a STORM COMPONENT, in kilometers. Precise to 10^{-4} kilometers.

SLEN = SHAPE (length), the distance between the points located by the beginning AZIMUTH RANGE (Slant) and the first azimuth of a STORM COMPONENT, and the ending AZIMUTH RANGE (Slant) and the last azimuth of a STORM COMPONENT, in kilometers. Precise to 10^{-4} kilometers.

SAX2 = SHAPE (AXIS2), the second axis of an ellipse defined by the SHAPE (Length) calculated from the area of the STORM COMPONENT, in kilometers. Precise to 10^{-4} kilometers.

SORI = SHAPE (Orientation), the orientation of the ellipse represented by SHAPE (Length) and SHAPE (AXIS2), in radians. Precise to 10^{-3} radians.

YC = Y-POSITION(Centroid), Y-position of a STORM CENTROID (center of mass), in kilometers. Precise to 10^{-4} kilometers.

XC = X-POSITION(Centroid), X-position of the STORM CENTROID (center of mass), in kilometers. Precise to 10^{-4} kilometers.

SELP = SHAPE (Ellipticity), the ratio of the axis length of the ellipse defined by SHAPE (Length) and SHAPE (AXIS2). A dimensionless quantity ranging between 0 to 1.

RCOE = RADIUS CORRECTION (Earth), the factor by which the RADIUS (Earth) is multiplied to account for refraction of the radar beam (1.21).

MSC = MASS (Storm Component), the mass weighted area of a STORM COMPONENT, in kg/km.

MWL = MASS WEIGHTED LENGTH, mass density weighted length of a STORM SEGMENT, in kg/km^2.

X = X-POSITION, X-position of the CENTROID, in kilometers. Precise to 10^{-4} kilometers.

MWS = MASS WEIGHTED LENGTH SQUARED, mass density weighted length squared of a STORM SEGMENT, in kg/km.

AZ = AZIMUTH, azimuthal position, in radians. Precise to 10^{-3} radians.

PHI# = ELEVATION, elevation angle, in radians. Precise Precise to 10^{-3} radians.

Y = Y-POSITION, Y-position of CENTROID, in kilometers. Precise to 10^{-4} kilometers.

CED = CENTROID DISTANCE, the distance or radius of a STORM COMPONENT, in kilometers. Precise to 10^{-4} kilometers.

MCD = MAXIMUM CENTROID DISTANCE, the maximum centroid distance for the STORM COMPONENT at the previous or next previous elevation, in kilometers. Precise to 10^{-4} kilometers.

Xdif1 = first X-POSITION difference. X-position difference between STORM COMPONENTs at adjacent ELEVATIONs, in kilometers. Precise to 10^{-4} kilometers.

Xdif2 = second X-POSITION difference, X-position difference between STORM COMPONENTs at non-adjacent ELEVATIONs, in kilometers. Precise to 10^{-4} kilometers.

Ydif1 = first Y-POSITION difference, Y-position difference between STORM COMPONENTs at adjacent ELEVATIONs, in kilometers. Precise to 10^{-4} kilometers.

Ydif2 = second Y-POSITION difference, Y-position difference between STORM COMPONENTs at non-adjacent ELEVATIONs, in kilometers. Precise to 10^{-4} kilometers.

PI# = A mathematical constant (3.1416), unitless.

i = INDEX (Elevation), the index for ELEVATION.

MST = MASS (Storm), the mass weighted volume of a STORM, in kilograms. Precise to 10^{-3} kilograms.

HSCCdif = HEIGHT (Storm Component-Centroid) difference, height difference between centroids of STORM COMPONENTs at two separate ELEVATIONs, in kilometers. Precise to 10^{-4} kilometers.

HSCC = HEIGHT (Storm Component-Centroid), height of the centroid of a STORM COMPONENT at a particular ELEVATION above the ground, in kilometers. Precise to 10^{-4} kilometers.

STC = STORM COMPONENT, a group of SAMPLE VOLUMEs, contiguous with respect to range (STORM SEGMENTs) and azimuth, at the same elevation angle. More than one may exist at a given elevation.

RE = RADIUS (Earth), the radius of the Earth (6371), in kilometers. Precise to 10^{-4} kilometers.

A = AREA (Storm Component), area of a STORM COMPONENT at a particular ELEVATION, in km^2. Precise to 10^{-6} kilometers^2.

ST = STORM, a three-dimensional region composed of STORM COMPONENTs characterized by reflectivity values above a given threshold, ordered by mass weighted volume.

STuno = Unordered STORM, a three dimensional region composed of STORM COMPONENTs characterized by reflectivity values above a given threshold, unordered by mass weighted volume.

DBZE = REFLECTIVITY FACTOR (DBZE), the effective radar reflectivity factor of a SAMPLE VOLUME, in dBZe.

DBZEmax = maximum REFLECTIVITY FACTOR (DBZE), the maximum effective radar reflectivity factor, in dBZe.

PSTC = POSSIBLE COMPONENT, a group of SAMPLE VOLUMEs, which are possibly contiguous with respect to range (STORM SEGMENTs) and azimuth, at the same elevation angle. More than one may exist at a given elevation.

VD = VELOCITY (Doppler), Doppler velocities in a data SAMPLE VOLUME, in km/hr. Precise to .36 km/hr.

VDmax = maximum VELOCITY (Doppler), the maximum Doppler velocity value, in km/hr. Precise to .36 km/hr.

W = SPECTRUM WIDTH, spectrum width value, in km/hr. Precise to .36 km/hr.

Wmax = maximum SPECTRUM WIDTH, maximum spectrum width value, in km/hr. Precise to .36 km/hr.

ZSC = REFLECTIVITY(Storm Component), effective reflectivity value detected in an individual STORM COMPONENT, in dBZe.

ZSCmax = maximum REFLECTIVITY(Storm Component), maximum effective reflectivity value detected in an individual STORM COMPONENT, in dBZe.

Note: This algorithm was implemented using 32 bit precision at AFGL.

Note: Precision is to the units unless otherwise specified.

3.2.2 SYMBOLIC FORMULAS

COMPUTE (ADJACENCY)

ADJ = Maximum of

$$\{(TSL/RSS)/[1/n \sum_{n} [(RSSSend + RSSSbeg)/2]]/RSS\}/AZDE$$

or ADJACENCY (Minimum), where n is the STORM SEGMENT number.

Note: Use nearest integer value of ADJ.

COMPUTE (MASS (Storm Component))

$$MSC = \sum_{n} (MWL_n)(RSS)(AZDE)$$

where n is the number of STORM SEGMENTs in each STORM COMPONENT.

COMPUTE (X-POSITION)

$$X = 1/MSC \sum_{n} (MWS_n)\ (\sin(AZ_n))\ (RSS)\ (AZDE)\ (\cos \phi)$$

where n is the number of STORM SEGMENTs in each STORM COMPONENT.

COMPUTE (Y-POSITION)

$$Y = 1/MSC \sum_{n} (MWS_n) (\cos(AZ_n)) (RSS) (AZDE) (\cos \phi)$$

where n is the number of STORM SEGMENTs in each STORM COMPONENT.

COMPUTE (AREA (Storm Component))

$$A_{ni} = \sum_{m} (RSSSend_m - RSSSbeg_m)$$

$$[(RSSSend_m + RSSSbeg_m)/2] (AZDE)$$

where n is the STORM COMPONENT number and m is the STORM SEGMENT number.

COMPUTE (CENTROID DISTANCE)

$$CED = (A/\pi)^{0.5}$$

COMPUTE (MAXIMUM CENTROID DISTANCE)

MCD = CED for the STORM COMPONENT at the previous or second previous elevation.

COMPUTE (first X-POSITION difference)

$$Xdif1 = | X_{ni} - X_{m(i-1)} |$$

where n is the nth STORM COMPONENT at i elevation and m is the mth STORM COMPONENT at (i-1) elevation. Xdif1 is computed for each combination of X_{ni} and $X_{m(i-1)}$.

COMPUTE (first Y-POSITION difference)

$$Ydif1 = | Y_{ni} - Y_{m(i-1)} |$$

where n is the nth STORM COMPONENT at i elevation and m is the mth STORM COMPONENT at (i-1) elevation. Ydif1 is computed for each combination of Y_{ni} and $Y_{m(i-1)}$.

COMPUTE (second X-POSITION difference)

$Xdif2 = | X_{ni} - X_{m(i-2)} |$

where n is the nth STORM COMPONENT at i elevation and m is the mth STORM COMPONENT at (i-2) elevation. Xdif2 is computed for each combination of X_{ni} and $X_{m(i-2)}$.

COMPUTE (second Y-POSITION difference)

$Ydif2 = | Y_{ni} - Y_{m(i-2)} |$

where n is the nth STORM COMPONENT at i elevation and m is the mth STORM COMPONENT at (i-2) elevation. Ydif2 is computed for each combination of Y_{ni} and $Y_{m(i-2)}$.

COMPUTE (MASS (Storm))

$$MST = \sum_i (MSC_i)\ (HSCCdif_i)$$

where;

$$HSCCdif_i = (X_i^2 + Y_i^2)^{0.5}\ (\sin d\phi) / (\cos \phi_i)$$

$$\text{and } d\phi = (\phi_{i+1} - \phi_{i-1}) / 2$$

COMPUTE (X-POSITION(Centroid))

$$XC = 1/MST \sum_i (X_i)(MSC_i)(HSCCdif_i)$$

COMPUTE (Y-POSITION(Centroid))

$$YC = 1/MST \sum_i (Y_i)(MSC_i)(HSCCdif_i)$$

COMPUTE (HEIGHT(Storm))

$$HSTO = \frac{\sum_i (MSC_i)(HSCCdif_i)(HSCC_i)}{MST}$$

COMPUTE (HEIGHT (Storm Component-Centroid))

$$HSCC = \{[(X^2 + Y^2)/\cos^2\phi]/[2(RCOE)(RE)]\} +$$

$$\{(X^2 + Y^2)^{1/2}(\sin\phi/\cos\phi)\}$$

COMPUTE (maximum REFLECTIVITY FACTOR (DBZE))

$DBZEmax_i = DBZE_i$ if $DBZE_i > DBZEmax_i$

COMPUTE (maximum VELOCITY(Doppler))

$VDmax_i = |VD_i|$ if $|VD_i| > VDmax_i$

COMPUTE (maximum SPECTRUM WIDTH)

$Wmax_i = W_i$ if $W_i > Wmax_i$

COMPUTE (SHAPE (Length))

$$SLEN = (SXDIF^2_{ni} + SYDIF^2_{ni})^{1/2}$$

where,

$$SXDIF_{ni} = (ARSbeg_{ni})[\sin(AZbeg_{ni})] - (ARSend_{ni})[\sin(AZend_{ni})]$$

$$SYDIF_{ni} = (ARSbeg_{ni})[\cos(AZbeg_{ni})] - (ARSend_{ni})[\cos(AZend_{ni})]$$

COMPUTE (begin AZIMUTH RANGE (SLANT))

$$ARSbeg_n = (RSSSbeg_m + RSSSend_m)/2$$

where RSSSbeg is the beginning slant range and RSSSend is the ending slant range for the first azimuth of a Storm Component(n) comprised of Storm Segment(m).

COMPUTE (end AZIMUTH RANGE (SLANT))

$ARSend_n = (RSSSbeg_m + RSSSend_m)/2$

where RSSSbeg is the beginning slant range and RSSSend is the ending slant range for the last azimuth of a Storm Component(n) comprised of Storm Segment(m).

COMPUTE (SHAPE(AXIS2))

$SAX2_{ni} = (4)\ [(A_{ni})/SLEN_{ni}]/\pi$

where: (A) is the AREA (Storm Component)

COMPUTE (SHAPE (Orientation))

$SORI_{ni} = \tan^{-1}(SXDIF_{ni}/SYDIF_{ni})$

IF ($SLEN_{ni}$ less than $SAX2_{ni}$) THEN

$SORI_{ni} = SORI_{ni} + \pi/2.$

COMPUTE (SHAPE (Ellipticity))

$SELP_{ni} = SLEN_{ni}/SAX2_{ni}$

IF $SELP_{ni}$ is less than 1 THEN

$SELP_{ni} = 1/SELP_{ni}$

4.0 OUTPUTS

4.1 IDENTIFICATION

X-POSITION (Centroid) and Y-POSITION (Centroid) are locations of mass weighted volumetric centers of mass of identified storms.

STORM is a set of identifiers for storms detected, ranked in the order of their mass weighted volumes.

X-POSITION and Y-POSITION are the center of mass positions of a storm component.

MASS(Storm) is a computed quantity that is ranked in order of decreasing mass for each unordered STORM.

STORM COMPONENTs (containing HEIGHT (Storm Component-Centroid), AREA (Storm Component), maximum REFLECTIVITY FACTOR (DBZE), maximum REFLECTIVITY(Storm Component), maximum VELOCITY(Doppler) and maximum SPECTRUM WIDTH) is a set of groups of sample volumes contiguous with respect to range and azimuth at the same elevation angle. There may be more than one at each elevation angle.

REFLECTIVITY(Storm Component) is an effective reflectivity value in a STORM COMPONENT.

4.2 DISTRIBUTION

The outputs from this algorithm are extremely useful and can, therefore, be expected to be used for many applications. As an example, the location of the storms could be used by precipitation application algorithms to reduce the amount of data required to be processed. At AFGL, implementation of a technique uses outputs from this algorithm to track and forecast locations of storms. The referencing algorithms are described in STORM TRACKING [004] and STORM POSITION FORECAST [008] algorithm descriptions.

X-POSITION (Centroid), Y-POSITION (Centroid), and STORMs are intended for input to the STORM TRACKING [004] and STORM POSITION FORECAST [008] algorithms. MASS(Storm) is also input to the STORM TRACKING [004] algorithm.

X-POSITION, Y-POSITION, STORM COMPONENT, maximum REFLECTIVITY (Storm Component), REFLECTIVITY (Storm Component) [NOTE: maximum REFLECTIVITY(Storm Component) and REFLECTIVITY(Storm Component) are determined by the maximum REFLECTIVITY FACTOR(DBZE) computation], STORMs and AREA(Storm Component) are intended for input to the HAIL [012] algorithm.

STORMs, MASS(Storm), maximum REFLECTIVITY FACTOR(DBZE), maximum VELOCITY(Doppler), maximum SPECTRUM WIDTH, AREA(Storm Component), HEIGHT(Storm Component-Centroid), X-POSITION, and Y-POSITION are intended for input to the STORM STRUCTURE [009] algorithm.

5.0 INFERENCES

5.1 LIMITATIONS

This algorithm is designed for isolating storms defined by regions of high reflectivity. It has not been tested extensively in cases of widespread regions of light precipitation. Its performance under these conditions is unknown.

VERTICALLY-INTEGRATED LIQUID WATER

ALGORITHM DESCRIPTION

NX-DR-03-006/24

MAJOR REVISIONS SINCE MAY 1984

Vertically-Integrated Liquid Water (006)

1. All algorithms appearing in the May 1984 report have undergone the following changes:

   a. Editorial and typographical changes.

   b. Explicit declaration of data element precision.

   c. Renaming of data element names and symbols to achieve unique naming.

   d. Data Dictionary changes resulting from other changes.

2. The definition of the fifteen categories was clarified by specifying that the Operational Threshold column of Table 1 was to be used.

3. All references to dBZ were changed to dBZe.

4. In section 1.3, 18.3 dBZ was changed to 18.5 dBZe.

5. VIL was originally written for the WSR-57's 2 degree beam width. In this version it has been adapted to NEXRAD's 1 degree beam width.

1.0 PROLOGUE

1.1 FUNCTIONAL DESCRIPTION

The Vertically-Integrated Liquid Water (VIL) algorithm describes the conversion of weather radar reflectivity data into liquid-water content based on theoretical studies of drop-size distributions and empirical studies on the relationship between reflectivity factor and liquid-water content. The algorithm described uses an equation which relates reflectivity factor to liquid-water content as given in the reference stated in Section 1.2. Large values of liquid-water content have been related to severe thunderstorms and tornadoes.

The VIL algorithm computes a liquid water value for each sample volume. Each sample volume is then mapped onto a predetermined 4 by 4 kilometer grid. For each elevation angle, each grid box is assigned the largest liquid water value of all the sample volumes located within the grid box. All other liquid water values in each grid box are ignored. This reduces data storage requirements while compensating for the fact that the storm is moving during the acquisition of the volume scan. Moreover, at distant ranges the sample volume size approaches the size of the grid box. These partial liquid water values are then integrated vertically to arrive at VIL values for each grid box. If the VIL value for a grid box exceeds 80 kg/m^2 it is adjusted to 80 kg/m^2 to mitigate the large reflectivity values associated with hail. NOTE: With the exception of this threshold VIL value (80 kg/m^2) all of the denominators for VIL values in this algorithm are in kilometers. The above VIL value in kilometers is 80 x 10^6 kg/km^2.

1.2 SOURCE

The VIL algorithm described herein has been implemented for the D/RADEX experiment conducted by the National Weather Service (NWS). Mr. Robert Saffle of the NWS's Techniques Development Laboratory supplied the D/RADEX information.

REFERENCES

Greene, D.R., and R.A. Clark, 1971: An indicator of explosive development in severe storms. Preprints, 7th Conference on Severe Local Storms (Kansas City), American Meteorological Society, Boston, 97-104.

Rogers, R.R., 1969: Interpretation of the fluctuating echo from randomly distributed scatterers. Part 4, Sci. Rept. MW-63, Stormy Weather Group, McGill University, Montreal.

1.3 PROCESSING ENVIRONMENT

This algorithm does not use the "raw" reflectivity factor data obtained from the radar. Several preprocessing steps are carried out before the data are input to VIL algorithm. The NWS preprocessing performed on the data is described by the following operations.

First the standard $1/r^2$ range correction is performed on the data. A correction is then made for oxygen absorption of microwave energy. The linear attenuation correction of 6.5×10^{-3} dB/km for a 10 cm radar is then performed. The resulting reflectivity factor data values for each sample volume are assigned a number representing fifteen categories as shown in the Operational Threshold column of Table 1. If the return power is less than 18.5 dBZe it is assigned a value of zero. The categorization of the data is performed so that a look-up table procedure can be used to arrive at liquid water values. The data are also filtered to remove any spurious data. A data point must have at least two adjacent points with a category value of at least one, otherwise the isolated point is removed. That is, at least two of the four possible sample volumes at a particular elevation with adjoining sides to the sample volume in question must be in category one or above. This final data set is the one used as input to the VIL algorithm.

Table 1. Values of reflectivity, rainfall rate, and liquid water content for RADAP II reflectivity intensity categories.

RADAP II VALUE	VIP VALUE	THRESHOLD ZE (mm^6/m^3)	THRESHOLD LOG ZE	OPERATIONAL THRESHOLD dBZe	THRESHOLD DVIP VALUE 1/2 dBZe	THRESHOLD R(200)* (in/hr)	MID-POINT ZE (mm^6/m^3)	MID-POINT LOG ZE	MID-POINT R(200)* (in/hr)	MID-POINT R(55)** (in/hr)	MID-POINT M**** (g/m^3)
1	1	68	1.83	18.5	37	.02	182	2.26	.04	.08	0.0
2		295	2.47	24.5	49	.05	593	2.77	.08	.16	0.1
3	2	891	2.95	29.5	59	.10	2140	3.33	.17	.39	0.3
4		3388	3.53	35.5	71	.23	5153	3.71	.30	.67	0.5
5		6918	3.84	38.5	77	.36	9309	3.97	.44	.97	0.6
6	3	11700	4.07	40.5	81	.50	15150	4.18	.59	1.32	0.8
7		18600	4.27	42.5	85	.67	19950	4.30	.70	1.57	1.0
8		21300	4.33	43.5	87	.83	28400	4.45	.87	1.94	1.2
9	4	35500	4.55	45.5	91	1.00	45850	4.66	1.18	2.63	1.6
10		56200	4.75	47.5	95	1.33	67800	4.83	1.50	3.36	2.0
11		79400	4.90	49.0	98	1.66	93200	4.97	1.84	4.11	2.4
12	5	107000	5.03	50.5	101	2.00	155500	5.19	2.52	5.64	3.2
13		204000	5.31	53.0	106	3.00	264000	5.42	3.51	7.86	4.3
14		324000	5.51	55.0	110	4.00	396000	5.60	4.55	7.86***	5.4
15	6	468000	5.67	56.5	113	5.00				7.86***	5.4***

* $Z = 200R^{1.6}$ ** $Z = 55R^{1.6}$ *** Lower category values used to minimize effects of hail   **** $M = 3.44 \times 10^{-3} Z^{4/7}$

2.0 INPUTS

2.1 IDENTIFICATION

AZIMUTH = Azimuthal position, in radians. Precise to 10^{-3} radians.

BEAM WIDTH = The angular width of the radar beam between the half-power points (0.017), in radians.

BOX (4 x 4 km Grid) = Square grid boxes which are 4 km on a side and cover ranges for 0 to 230 km.

CATEGORIES = Categorized effective reflectivity factor data for each SAMPLE VOLUME.

ELEVATION = Elevation angle, in radians.

RANGE (Slant) = The slant range to the center of a SAMPLE VOLUME, in kilometers.

2.2 ACQUISITION

AZIMUTH, ELEVATION, and RANGE (Slant) are quantities measured directly during the radar data acquisition process.

BEAM WIDTH is a constant determined by the antenna's characteristic beam width.

BOX (4 x 4 km Grid) is a system supplied parameter.

CATEGORIES is obtained from a preprocessing function as described in Section 1.3.

3.0 PROCEDURE

3.1 ALGORITHM

```
BEGIN ALGORITHM (VIL)

1.0  DO FOR ALL (ELEVATIONs)
     1.1  DO FOR ALL (AZIMUTHs)
          1.1.1  DO FOR ALL (RANGEs (Slant))
                 1.1.1.1  COMPUTE (LIQUID WATER)
                 1.1.1.2  Map polar position of CATEGORIES
                          onto a BOX (4 x 4 kilometer Grid).
                 1.1.1.3  COMPUTE (DEPTH (Beam))
                 END DO
          END DO
     1.2  DO FOR ALL (BOXes (4 x 4 km Grid))
          1.2.1  COMPUTE (maximum LIQUID WATER)
          1.2.2  COMPUTE (partial VIL)
          1.2.3  COMPUTE (LIQUID WATER (Integrated))
                 WRITE (LIQUID WATER (Integrated))
          1.2.4  IF (LIQUID WATER (Integrated) is greater
                    than 80)
                    THEN (Assign LIQUID WATER (Integrated)
                         to be 80)
                 END IF
          END DO

     END DO

2.0  COMPUTE (maximum LIQUID WATER (Integrated))

3.0  WRITE (maximum LIQUID WATER (Integrated))

END ALGORITHM (VIL)
```

3.2 COMPUTATION

3.2.1 NOTATION

LW = LIQUID WATER, the liquid water content for a particular value of reflectivity, in kg/km^3.

ZE = REFLECTIVITY FACTOR (ZE), the effective radar reflectivity factor of a SAMPLE VOLUME, in mm^6/m^3.

DB = DEPTH (Beam), the depth of the radar beam as a function of range for each grid box, in kilometers. Precise to 10^{-4} kilometers.

RH = RANGE (Horizontal), the horizontal range, in kilometers. Precise to 10^{-4} kilometers.

RE = RADIUS (Earth), the radius of the Earth (6371), in kilometers. Precise to 10^{-4} kilometers.

BW = BEAM WIDTH, the angular width of the radar beam between the half-power points (.017), in radians. Precise to 10^{-3} radians.

RS = RANGE (Slant), the slant range to the center of a SAMPLE VOLUME, in kilometers. Precise to 10^{-4} kilometers.

PHI# = ELEVATION, elevation angle, in radians. Precise to 10^{-3} radians.

LWmax = maximum LIQUID WATER, the maximum liquid water content found within a grid box, in kg/km^3.

VILpar = partial LIQUID WATER (Integrated), the portion of the LIQUID WATER (Integrated) in a column which is detected at a particular elevation (per grid box) within a storm, in kg/km^2.

VIL = LIQUID WATER (Integrated), integrated liquid water values (per grid box) for a column within a STORM, in kg/km^2.

VILmax = maximum LIQUID WATER (Integrated), the maximum LIQUID WATER (Integrated) value in the scanning region, in kg/km^2.

NOTE: Precision is to the units specified unless otherwise stated.

3.2.2 SYMBOLIC FORMULAS

COMPUTE (LIQUID WATER)

$LW = 3.44 \times 10^3 \; ZE^{4/7}$

COMPUTE (DEPTH (Beam))

IF lowest elevation scan

THEN $DB = RH(TAN(\phi \; avg)) + RH^2/[2(4/3)(RE)(COS^2 \phi \; avg)]$

Where $\phi \; avg = (\phi_1 + \phi_2)/2$

```
ELSE IF highest elevation scan
  THEN $DB = 1/2 (RH)(TAN(\phi_{top} + (BW)/2) - TAN(\phi_{top-1}))$
ELSE
  $DB = 1/2 (RH)(TAN(\phi_{i+1}) - TAN(\phi_{i-1}))$
END IF
```

Where top is the highest elevation scan in the volume sequence.

```
COMPUTE (maximum LIQUID WATER)
$LWmax = LW_n$ if $LW_n > LWmax$
     where n is the number of LW values within a BOX.
COMPUTE (partial VIL)
$VILpar = (LWmax)(DB)$
COMPUTE (LIQUID WATER (Integrated))
$VIL = \sum_i VILpar_i$
COMPUTE (maximum LIQUID WATER (Integrated))
$VILmax = VIL_n$ if $VIL_n > VILmax$
    where n is the number of BOXes.
```

4.0 OUTPUTS

4.1 IDENTIFICATION

A set of LIQUID WATER (Integrated) values corresponding to the BOXes (4 x 4 km Grid).

The maximum LIQUID WATER (Integrated) value for each complete volume scan is output.

4.2 DISTRIBUTION

The vertically-integrated liquid water content values could be used by an algorithm to plot contours of the values. The data can also be used to derive a severe weather probability index. Another use is tracking storms by their maximum VIL. The LIQUID WATER (Integrated) values are input to the SEVERE WEATHER PROBABILITY [015] algorithm.

5.0 INFERENCES

5.1 LIMITATIONS

This algorithm will have a bias towards larger drop sizes. Clouds containing a large number of small drops produce very small values of ZE, which could be below the detectable signal level of the radar. This is, however, rarely a problem in most severe weather cases. Also, hail can produce fictitious values of liquid water due to enhanced reflectivity values. Therefore, a maximum value of 80 kg/m^2 is set as a ceiling to mitigate this effect.

This current implementation has no earth curvature correction, i.e., the earth is considered flat when mapping data in polar coordinates to the rectilinear coordinates. The values obtained at distant ranges may be misleading because liquid water below the radar beam is not measured. At long ranges, errors may be due to large sample volumes also.

5.2 FUTURE DEVELOPMENTS

There is no knowledge of future plans to modify the VIL algorithm in its current implementation.

VELOCITY-AZIMUTH DISPLAY

ALGORITHM DESCRIPTION

NX-DR-03-007/29

MAJOR REVISIONS SINCE MAY 1984

Velocity Azimuth Display (007)

1. All algorithms appearing in the May 1984 report have undergone the following changes:

   a. Editorial and typographical changes.

   b. Explicit declaration of data element precision.

   c. Renaming of data element names and symbols to achieve unique naming.

   d. Data Dictionary changes resulting from other changes.

2. In the May 1984 version, the Velocity Azimuth Display (VAD) Algorithm computed one velocity per tilt--each at the specified VAD RANGE. This was a necessary evil. Necessary because vertical velocity estimates must all be taken at the same range. Evil because the elevations of the horizontal winds could not be controlled. This problem has now been solved by introducing VAD Analysis Ranges which is the set of specific slant range(s) for each tilt at which horizontal wind will be computed. VAD RANGE, which will be a subset of VAD Analysis Ranges, continues to be a fixed range thus permitting accuracy in the vertical winds. Though this has resulted in logic changes, the actual VAD computation for an individual wind has not been changed.

3. Errors in equations for ROOT MEAN SQUARE, DIVERGENGE (Horizontal), Q1, Q2, VPF and FIT have been corrected.

4. Added THRESHOLD (Data Points) to the list of adaptable parameter.

5. The following WRITEs have been deleted: HEIGHT, FIT TESTS, TIME (Scan) and HEIGHT (VAD Wind Estimates).

1.0 PROLOGUE

1.1 FUNCTIONAL DESCRIPTION

The Velocity-Azimuth Display (VAD) algorithm is used to obtain the vertical profile of horizontal wind speed, direction, divergence and vertical velocity for the region of the atmosphere surrounding a Doppler radar. Velocity data at different azimuths collected from a Doppler radar scanning the atmosphere at a constant elevation angle about a vertical axis is used. This algorithm performs a harmonic analysis along with a best fit test on the Doppler velocities around the circumference of a circle at a specified slant range to obtain these parameters. The vertical wind velocity is obtained through a series of steps involving the relationship between horizontal wind speed and conservation of mass through a constant elevation surface above the radar.

1.2 SOURCE

The Velocity-Azimuth Display algorithm is the result of theoretical studies first performed by Lhermitte and Atlas (1961). Rabin and Zrnic (1980) applied the VAD technique to an environment void of precipitation (clear air) with excellent results. The algorithm described here was developed at the National Severe Storms Laboratory (NSSL) at Norman, Oklahoma, by Rabin and Zrnic.

REFERENCES

Lhermitte, R.M., and D. Atlas, 1961: Precipitation motion by pulse Doppler. Proc. Ninth Weather Radar Conf., Boston, Amer. Meteor. Soc., 218-223.

Rabin, R.M., and D. Zrnic, 1980: Subsynoptic-scale vertical wind revealed by dual Doppler-radar and VAD analysis. J. Atmos. Sci., 37, 644-654.

Rabin, R.M., "Vertical Velocity Calculations from VAD", MEMO FOR THE RECORD, September 20, 1982. NSSL, Norman, Oklahoma.

1.3 PROCESSING ENVIRONMENT

This algorithm uses the data obtained by direct measurement of reflective power and Doppler velocity from a Doppler weather radar. The only preprocessing required before use is the elimination of bad data. The kinds of preprocessing include ground clutter elimination, anomalous propagation elimination, and elimination of data when echoes beyond the unambiguous range of the radar fold into the desired VAD analysis range. For clear air situations, Doppler velocities from adjacent sample volumes should be averaged to reduce scatter of Doppler velocity estimates caused by weak echoes. The velocity values should be thresholded on a signal-to-noise ratio (e.g.3dB) that is UCP adaptable.

2.0 INPUTS

2.1 IDENTIFICATION

AZIMUTH = Azimuthal position, in radians.

HEIGHT(Radar) = The radar height above sea level, in kilometers.

DENSITY (Atmospheric) = A set of density values for each altitude, in kg/km^3.

DENSITY (Atmospheric Gradient) = A set of density gradient values at each altitude, in kg/km^4.

ELEVATION = Elevation angle, in radians.

FIT TESTS = The number of times the fit test procedure is to be run (2).

REFLECTIVITY FACTOR (ZE) = The effective radar reflectivity factor of a SAMPLE VOLUME, in mm^6/m^3.

THRESHOLD (Begin Azimuth) = Starting azimuth for VAD analysis, in radians.

THRESHOLD (Data Points) = The minimum number of data points allowed for the Fourier least squares fitting, unitless (25).

THRESHOLD (End Azimuth) = Ending azimuth for VAD analysis, in radians.

THRESHOLD (Symmetry) = A value for determining symmetry, in km/hr (25.2).

THRESHOLD (Velocity) = A RMS velocity threshold (18), in km/hr.

TIME (Scan) = The beginning time of a scan, in hours. Precise to 1/3600 hr.

VAD (Analysis Ranges) = The set of specific slant range(s) for each elevation angle at which horizontal wind estimates are computed. The VAD Range is included in the VAD (Analysis Ranges), in 1/4 kilometers.

VAD RANGE = The subset of VAD (Analysis Ranges) used to compute estimates of vertical velocity and divergence, in 1/4 kilometers.

VELOCITY (Doppler) = Doppler velocities in a SAMPLE VOLUME, in km/hr.

2.2 ACQUISITION

DENSITY (Atmospheric) and DENSITY (Atmospheric Gradient) are acquired through direct measurements or standard tables.

FIT TESTS is a system supplied parameter.

VELOCITY (Doppler) is acquired by direct Doppler radar measurement.

ELEVATIONs and AZIMUTHs are obtained by direct measurement of radar antenna pointing direction.

REFLECTIVITY FACTOR (ZE) is acquired directly from the Doppler radar hardware.

HEIGHT(Radar) is a scientifically determined parameter which is site specific.

THRESHOLD (End Azimuth), THRESHOLD (Begin Azimuth), THRESHOLD (Symmetry), THRESHOLD (Velocity), THRESHOLD (Data Points) and VAD RANGE are operator supplied parameters.

TIME (Scan) is acquired by direct measurement.

VAD Analysis Range is a system supplied parameter derived from the reporting altitudes of the VAD Winds product.

3.0 PROCEDURE

3.1 ALGORITHM

```
BEGIN ALGORITHM (VAD)

1.0  DO FOR ALL (ELEVATIONs)
     DO FOR (VAD Analysis Range at each ELEVATION)
     1.1  DO FOR ALL (FIT TESTS)
             COMPUTE (COEFFICIENT (Fourier, #1))
             COMPUTE (COEFFICIENT (Fourier, #2))
             COMPUTE (COEFFICIENT (Fourier, #3))
             COMPUTE (DIRECTION (Wind))
             COMPUTE (ROOT MEAN SQUARE)
             COMPUTE (SPEED (Wind))
             DO FOR ALL (AZIMUTHs between THRESHOLD (Begin
                        Azimuth) and THRESHOLD (End Azimuth))
                COMPUTE (FIT)
                IF (FIT is greater than zero)
                   THEN
                      IF (FIT minus the current VELOCITY
                         (Doppler) is greater than ROOT MEAN
                         SQUARE)
                         THEN (set current VELOCITY
                              (Doppler) as missing)
                      END IF
                   ELSE
                      IF (current VELOCITY (Doppler) minus
                         FIT is greater than ROOT MEAN
                         SQUARE)
                         THEN (set current VELOCITY
                              (Doppler) as missing)
                      END IF
                END IF

                WRITE (COEFFICIENT (Fourier, #1))
                WRITE (COEFFICIENT (Fourier, #2))
                WRITE (COEFFICIENT (Fourier, #3))
                WRITE (ROOT MEAN SQUARE)
                WRITE (DIRECTION (Wind))
                WRITE (FIT)
                WRITE (NUMBER (Data Points))
             END DO
          END DO
     1.2  COMPUTE (SYMMETRY)
     1.3  COMPUTE (HEIGHT (VAD Wind Estimate))
          IF (ROOT MEAN SQUARE is less than THRESHOLD (Velocity)
             AND fit is symmetric (SYMMETRY) and NUMBER (Data
             Points) is greater than THRESHOLD (Data Points))
             THEN COMPUTE (Speed Horizontal Wind))
                  WRITE (HEIGHT (VAD Wind Estimate))
                  WRITE (SPEED (Horizontal Wind))
                  WRITE RANGE (Slant)
                  WRITE ELEVATION
                IF (VAD Analysis Range equals VAD Range)
                  THEN
                    COMPUTE (VELOCITY (Precipitation Fall))
                    COMPUTE (DISTANCE (Earth Center))
                    COMPUTE (AREA (Surface))
                    COMPUTE (AREA (Surface Change))
                    COMPUTE (SPEED (Vertical Wind Change))
                    COMPUTE (SPEED (Vertical Wind))
                    COMPUTE (DIVERGENCE (Horizontal))
                    WRITE (DIVERGENCE(Horizontal))
                    WRITE (SPEED(Vertical Wind))
                END IF
          END IF
     END DO
 END DO

END ALGORITHM (VAD)
```

3.2 COMPUTATION

3.2.1 NOTATION

ALT = ALTITUDE, the height above sea level, in km. Precise to 0.1 kilometers.

CF1 = COEFFICIENT (Fourier, #1), the Fourier series coefficient #1 that allows for the best possible approximation of a function, in km/hr. Precise to 0.1 km/hr.

CF2 = COEFFICIENT (Fourier, #2), the Fourier series coefficient #2 that allows for the best possible approximation of a function, in km/hr. Precise to 0.1 km/hr.

CF3 = COEFFICIENT (Fourier, #3), the Fourier series coefficient #3 that allows for the best possible approximation of a function, in km/hr. Precise to 0.1 km/hr.

j = INDEX (Azimuth), the index for AZIMUTH.

VD = VELOCITY (Doppler), Doppler velocities in a SAMPLE VOLUME, in km/hr. Precise to 0.1 km/hr.

AZ = AZIMUTH, azimuthal position, in radians. Precise to 10^{-3} radians.

DW = DIRECTION (Wind), the horizontal direction from which the wind is flowing, in radians. Precise to 10^{-3} radians.

RMS = ROOT MEAN SQUARE, the square root of mean squared deviations of Doppler velocities from a Fourier least-squares fit curve, in km/hr. Precise to 0.1 km/hr.

SHW = SPEED (Horizontal Wind), horizontal wind speed, in km/hr. Precise to 0.1 km/hr.

SPW = SPEED (Wind), the horizontal wind speed not corrected for the elevation angle of measurement, in km/hr. Precise to 0.1 km/hr.

FIT = FIT, the Doppler velocity value at a given azimuth angle on the Fourier least squares fitted curve, in km/hr. Precise to 0.1 km/hr.

PHI# = ELEVATION, elevation angle, in radians. Precise to 10^{-3} radians.

HVAD = HEIGHT (VAD Wind Estimate), the height above the ground level from which data was collected, in kilometers. Precise to 0.1 kilometers.

RS = RANGE (Slant), the slant range to the center of a SAMPLE VOLUME, in kilometers. Precise to 0.1 kilometers.

RE = RADIUS (Earth), the radius of the Earth (6371), in kilometers. Precise to 10^{-4} kilometers.

VPF = VELOCITY (Precipitation Fall), the precipitation fall velocity, in km/hr. Precise to 0.1 km/hr.

ZE = REFLECTIVITY FACTOR (ZE), the effective radar reflectivity factor of a SAMPLE VOLUME, in mm^6/m^3.

HR = HEIGHT (Radar), the radar height above sea level, in kilometers. Precise to 0.1 kilometers.

DIV = DIVERGENCE (Horizontal), horizontal divergence, in 1/hr. Precise to 10^{-2} hr^{-1}.

DEC = DISTANCE (Earth Center), the distance from the Earth center, in km. Precise to 0.1 kilometers.

i = INDEX (Elevation), the index for ELEVATION.

AS = AREA (Surface), the surface area in the plane above the radar bounded by the VAD analysis range, in km^2.

ASC = AREA (Surface Change), the rate of change of AREA (Surface) with respect to height, in km^2/km or kilometers. Precise to 0.1 kilometers.

SVC = SPEED (Vertical Wind Change), the rate of change of the vertical wind speed at a specific altitude, in (km/hr)/km or 1/hr.

PI# = PI, a mathematical constant (3.1416), unitless.

RHO# = DENSITY (Atmospheric), a set of density values for each altitude, in kg/km^3. Precise to 10^6 kg/km^3.

DRHO# = DENSITY (Atmospheric Gradient), a set of density gradient values at each altitude, in kg/km^4. Precise to $10^6 kg/km^4$.

SVW = SPEED (Vertical Wind), the vertical wind speed speed (positive upward), in km/hr. Precise to $10^{-3} km/hr$.

ND = NUMBER (Data Points), the number of non-missing data points between THRESHOLD (Begin Azimuth) and THRESHOLD (End Azimuth) that went into the Fourier least squares fitting.

SYMM = SYMMETRY, a flag value that is positive if the absolute value of COEFFICIENT(Fourier, #1) is less than the THRESHOLD(Symmetry) and the absolute value of COEFFICIENT(Fourier, #1) minus SPEED(Wind) is less than or equal to zero.

Note: Precision is equivalent to the units unless otherwise stated.

3.2.2 SYMBOLIC FORMULAS

COMPUTE (COEFFICIENTS (Fourier))

$$CF1 = [(1/ND) \sum_j VD_j] - 2\ REL\{[(Q1-(Q2)(Q1)^{COM})/(1-|Q2|^2)]Q4\}$$

$$CF2 = REL\{(Q1-(Q2)(Q1)^{COM})/(1-|Q2|^2)\}$$

$$CF3 = IM\{(Q1-(Q2)(Q1)^{COM})/(1-|Q2|^2)\}$$

where IM is the imaginary part of a complex variable, REL is the real part and

$$Q1 = \{[(1/ND) \sum_j VD_j] - (Q3)/[2(Q4)^{COM}]\}/\{Q4-[1/(4\ (Q4)^{COM})]\}$$

$$Q2 = \{Q4^{COM}-[(Q5)/(2(Q4)^{COM})]\}/\{Q4-[1/(4(Q4)^{COM})]\}$$

$$Q3 = (1/ND) \sum_j VD_j\ [\cos(AZ_j) - (-1)^{0.5} \sin(AZ_j)]$$

$$Q4 = [1/2ND] \sum_j [\cos(AZ_j) + (-1)^{0.5} \sin(AZ_j)]$$

$$Q5 = [1/2ND] \sum_j [\cos(2AZ_j) - (-1)^{0.5} \sin(2AZ_j)]$$

Where COM denotes a complex conjugate, ND is the number of non-missing data points between THRESHOLD (Begin Azimuth) and THRESHOLD (End Azimuth) that went into the Fourier least squares fitting, and j varies between THRESHOLD (Begin Azimuth) and THRESHOLD (End Azimuth).

COMPUTE (DIRECTION (Wind))

$$DW = [\pi - \tan^{-1}(CF3/CF2)] \text{ for } \tan^{-1} = 0 \text{ to } \pi$$

*if DW is less than 0:

$$DW\ (<0) = DW + 2\pi$$

NOTE: $\pi = 3.1416$

COMPUTE (ROOT MEAN SQUARE)

$$RMS = \{1/ND \sum_j [-\cos(AZ_j - DW)(CF2^2 + CF3^2)^{1/2} + CF1 - VD_j]^2\}^{1/2}$$

where ND is the number data points on the VAD circumference and j (the summation index) varies between THRESHOLD (Begin Azimuth) and THRESHOLD (End Azimuth).

COMPUTE (SPEED (Wind))

$$SPW = [(CF2)^2 + (CF3)^2]^{0.5}$$

COMPUTE (FIT)

$$FIT_j = [-\cos(AZ_j - DW)(SPW)] + CF1$$

COMPUTE (SYMMETRY)

Positive (symmetric) if |CF1| is less than THRESHOLD (Symmetry) AND |CF1| - SPW is less than or equal to zero.

COMPUTE (SPEED (Horizontal Wind))

$$SHW = (CF2^2 + CF3^2)^{1/2} / \cos(\phi)$$

COMPUTE (HEIGHT (VAD Wind Estimate))

$$HVAD = \{RS + [2(4/3\ RE)(RS) \sin \phi]\} / 2(4/3\ RE)$$

COMPUTE (VELOCITY (Precipitation Fall))

For liquid precipitation,

$$VPF = 9.54 (ZE^{0.114}) [1.01091 + (HVAD + HR)(0.02863) + (HVAD + HR)^2\ 0.00259]$$

For snow,

$$VPF = 2.94\ ZE^{0.063}$$

For clear air,

$$VPF = 0$$

COMPUTE (DISTANCE (Earth Center))

$$DEC_i = RE - E + E\,[1 + (RS/E)^2 + 2RS/E \sin \phi]^{0.5}$$

where: $E = 4/3\ RE$

COMPUTE (AREA (Surface))

$$AS_i = 2\pi (DEC_i)^2 [1 - \cos Q6_i]$$

where:

$$Q6_i = 4/3 \cos^{-1} \left[\frac{E^2 + (DEC_i + RE/3)^2 - RS^2}{2E(DEC_i + RE/3)} \right]$$

NOTE: $DEC_o = RE$

COMPUTE (AREA (Surface Change))

$$ASC_i = \frac{2AS_i}{DEC_i} - \left\{ \frac{\pi (DEC_i)^2 \sin(Q6_i)}{(RE) \sin(3/4 Q6_i)} \left[1 + \frac{RS^2 - E^2}{(DEC_i + RE/3)^2} \right] \right\}$$

COMPUTE (SPEED (Vertical Wind Change))

$$\overset{*}{SVC_i} = -3/2 \frac{(\pi)(RS)}{RE} [DEC_i + RE/3] \frac{CF1_i}{AS_i} - \left[\frac{1}{AS_i} ASC_i + \frac{1}{RHO\#_i} DRHO\#_i \right] SVW_{i-1}$$

(assume $SVW_{i-1} = 0$ for $i = 1$)

* : Use last good value of SVW_{i-1} if current value is not available.

COMPUTE (SPEED (Vertical Wind))

$SVW_i^* = SVW_{i-1} + (SVC_i)\ \Delta DEC$

where :

$\Delta DEC = DEC_i - DEC_{i-1}$

Assuming: $SVW_0 = 0$

COMPUTE (DIVERGENCE (Horizontal))

$DIV = 2(CF1_{ih})/[(RS)(COS\ \phi_i)] + [2VPF\ \tan\phi_i\ /(RS)]$

Where:

$CF1_{ih} = CF1_i - (SVW_i)\ \sin\phi_i$

*: Use last good value of SVW_{i-1} if current value is not available.

4.0 OUTPUTS

4.1 IDENTIFICATION

DW is a table of horizontal wind direction as a function of height for this observation time.

SHW is a table of horizontal wind speed as a function of height for this observation time.

DIV is a table of horizontal divergence as a function of height for this observation time.

SVW is a table of vertical wind speed (positive upward) as a function of height for this observation time.

4.2 DISTRIBUTION

Outputs from the VAD algorithm can serve as inputs to a wind shear algorithm and a turbulence algorithm.

5.0 INFERENCES

5.1 LIMITATIONS

This version of the VAD algorithm does not account for deformation (e.g., fronts). The successful operation of this algorithm rests on the assumption that there are enough echoes to receive coherent Doppler velocity estimates. When operating in the clear air mode the VAD algorithm averages three sample volumes in range to reduce the scatter of Doppler velocities due to weak echo returns. There are many equations relating equivalent reflectivity to precipitation fall velocity. An incorrect relationship will cause errors in the estimates of horizontal divergence and vertical wind speed.

Compromises may need to be made in determining the optimum slant range for the VAD. At short ranges ground clutter can completely saturate data and at long ranges the resolution of the Doppler radar decreases.

5.2 FUTURE DEVELOPEMENTS

The only future development regarding the VAD algorithm is the determination of the values for velocity threshold and slant range. This will probably be done during the NEXRAD algorithm testing phase.

STORM POSITION FORECAST
ALGORITHM DESCRIPTION
NX-DR-03-008/25

MAJOR REVISIONS SINCE MAY 1984

Storm Position Forecast (008)

1. All algorithms appearing in the May 1984 report have undergone the following changes:

    a. Editorial and typographical changes.

    b. Explicit declaration of data element precision.

    c. Renaming of data element names and symbols to achieve unique naming.

    d. Data Dictionary changes resulting from other changes.

2. An unbalanced parenthesis in the Permissible ERROR compute has been corrected.

3. WRITE and COMPUTE added for mean TRACK ERROR.

4. The compute for DIRECTION (Storm) was corrected.

1.0 PROLOGUE

1.1 FUNCTIONAL DESCRIPTION

The purpose of the STORM POSITION FORECAST algorithm is to predict the future centroid locations of storms based on a history of the storm's movement. The prediction results from using a linear least squares extrapolation of the storm's previous positions. The first time a storm is detected it is labeled a new storm, but no prediction of movement is made. The next time a storm is detected by the STORM CENTROIDS [005] algorithm it is evaluated as to where the possible future positions of the storm could be based on the previous two positions. This process is continued each time a storm is tracked. However, the next position identified by STORM TRACKING [004] algorithm is checked against the previous forecast. The number of forecasts made at the current time is based upon the magnitude of this departure. The position of a storm is related to the position of its center of mass measured in a Cartesian coordinate system with radar at the origin, the X-axis indicates east-west directions, and the Y-axis indicates north-south directions. The algorithm performs linear least squares fits for both X-position versus time and Y-position versus time and quantifies the scatter about these fitted lines.

1.2 SOURCE

The STORM POSITION FORECAST algorithm has been implemented by Air Force personnel at the Air Force Geophysics Laboratory (AFGL) in Sudbury, Massachusetts.

REFERENCES

Bjerkaas, C.L., and D.E. Forsyth, 1980: An Automated Real-Time Storm Analysis and Storm Tracking Program (WEATRK). AFGL-TR-80-0316, Air Force Geophysics Laboratory, Hanscom AFB, Massachusetts 01731.

1.3 PROCESSING ENVIRONMENT

The STORM POSITION FORECAST algorithm is the final step in the storm movement prediction process. It utilizes information output by the STORM TRACKING [004] algorithm. Therefore, it cannot be applied until the completion of that analysis, which requires a complete volume scan of data.

2.0 INPUTS

2.1 IDENTIFICATION

ALLOWABLE ERROR = The maximum acceptable error in the track of a STORM allowed for the minimum forecast interval, in km/hr.

CORRELATION (Table) = A data set used to keep track of the positions of correlated STORMs.

ERROR INTERVAL = The amount of time upon which the ALLOWABLE ERROR was based, in hours.

FORECAST INTERVAL = A set of time intervals for which centroid positions may be projected into the future, in hours.

STORM = A three-dimensional region composed of STORM COMPONENTs characterized by reflectivity values above a given threshold, ordered by mass weighted volume.

X-POSITION (Centroid) = X-position of a STORM CENTROID (center of mass), in kilometers.

Y-POSITION (Centroid) = Y-position of a STORM CENTROID (center of mass), in kilometers.

TIME (Scan) = The beginning time of a scan, in hours.

2.2 ACQUISITION

CORRELATION (Table) is acquired from the STORM TRACKING [004] algorithm.

ALLOWABLE ERRORs, ERROR INTERVAL and FORECAST INTERVALs are site selective parameters.

STORM is obtained from a storm isolation algorithm such as the STORM CENTROID [005] algorithm.

TIME (Scan) is acquired by direct measurement from a Doppler radar.

X-POSITION (Centroid) and Y-POSITION (Centroid) are obtained from the STORM CENTROID [005] algorithm.

3.0 PROCEDURE

3.1 ALGORITHM

```
BEGIN ALGORITHM (STORM POSITION FORECAST)

1.0  DO FOR ALL (STORMs)
     1.1  COMPUTE (X-SPEED (Storm))
     1.2  COMPUTE (Y-SPEED (Storm))
     1.3  COMPUTE (FORECAST ERROR)
     1.4  COMPUTE (mean FORECAST ERROR)
     1.5  DO FOR ALL (FORECAST INTERVALs)
              COMPUTE (PERMISSIBLE ERROR)
              IF (FORECAST ERROR is less than PERMISSIBLE ERROR
                 for this particular FORECAST INTERVAL)
                 THEN
                    COMPUTE (forecasted X-POSITION(Centroid))
                    COMPUTE (forecasted Y-POSITION(Centroid))
                 ELSE Do not compute a forecast for this
                         storm.
              END IF
          END DO
     1.6  COMPUTE (SPEED (Storm))
     1.7  COMPUTE (DIRECTION (Storm))
     1.8  COMPUTE (TRACK VARIANCE(X-direction))
     1.9  COMPUTE (TRACK VARIANCE(Y-direction))
     1.10 WRITE (forecasted X-POSITION(Centroid))
     1.11 WRITE (forecasted Y-POSITION(Centroid))
     1.12 WRITE (SPEED (Storm))
     1.13 WRITE (DIRECTION (Storm))
     1.14 WRITE (FORECAST ERROR)
     1.15 WRITE (TRACK VARIANCE (X-direction))
     1.16 WRITE (TRACK VARIANCE (Y-direction))
     1.17 WRITE (X-SPEED (Storm))
     1.18 WRITE (Y-SPEED (Storm))
     1.19 WRITE (mean FORECAST ERROR)
     END DO

END ALGORITHM (STORM POSITION FORECAST)
```

3.2 COMPUTATION

3.2.1 NOTATION

XSpre = previous X-SPEED (Storm), the previous speed of a STORM in the X-direction, in km/hr. Precise to .36 km/hr.

YSpre = previous Y-SPEED (Storm), the previous speed of a STORM in the Y-direction, in km/hr. Precise to .36 km/hr.

TScur = current TIME (Scan), the current scan time, in hours. Precise to 1/3600 hr.

XCpre = previous X-POSITION (Centroid), the previous STORM position in the X-direction, in kilometers. Precise to 10^{-4} kilometers.

YCpre = previous Y-POSITION (Centroid), the previous STORM position in the Y-direction, in kilometers. Precise to 10^{-4} kilometers.

VX = TRACK VARIANCE (X-direction), the variance in the STORM position in the X-direction from least squares calculations, in km. Precise to 10^{-4} km.

VY = TRACK VARIANCE (Y-direction), the variance in the STORM position in the Y-direction from least squares calculations, in km. Precise to 10^{-4} km.

PE = PERMISSIBLE ERROR, the maximum error allowed in the forecast of a STORM for each forecast interval, in kilometers. Precise to 10^{-4} kilometers.

AER = ALLOWABLE ERROR, the maximum error in the track of a STORM allowed during the ERROR INTERVAL, in kilometers. Precise to 10^{-4} kilometers.

EI = ERROR INTERVAL, the amount of time upon which the ALLOWABLE ERROR was based, in hours. Precise to 1/3600 hr.

CVX = X-COEFFICIENT, a coefficient of track variability in the X-direction, in km^2. Precise to 10^{-6} km^2.

CVY = Y-COEFFICIENT, a coefficient of track variability in the Y-direction, in km^2. Precise to 10^{-6} km^2.

XCfor = forecasted X-POSITION (Centroid), forecasted STORM CENTROID position in the X-direction, in kilometers. Precise to 10^{-4} kilometers.

XCcur = current X-POSITION (Centroid), current STORM position in the X-direction, in kilometers. Precise to 10^{-4} kilometers.

XS = X-SPEED (Storm), the speed of a STORM in the X-direction, in km/hr. Precise to .36 km/hr.

XC = X-POSITION (Centroid), X-position of a STORM CENTROID (center of mass), in kilometers. Precise to 10^{-4} kilometers.

FI = FORECAST INTERVAL, a set of time intervals for which centroid positions may be projected into the future, in hours. Precise to 1/3600 hr.

XCavg = average X-POSITION (Centroid), average STORM position in the X-direction from the CORRELATION (Table), in kilometers. Precise to 10^{-4} kilometers.

FE = FORECAST ERROR, the departure of the current STORM position from the position forecasted for that STORM at the previous time, in km. Precise to 10^{-4} km.

FEmean = mean FORECAST ERROR, the average FORECAST ERROR of a STORM (refers to a single STORM over its entire life-time), in kilometers. Precise to 10^{-4} kilometers.

TS = TIME (Scan), the beginning time of a scan, in hours. Precise to 1/3600 hr.

TSavg = average TIME (Scan), the average of all TIMEs (Scan) in the forecast period, in hours. Precise to 1/3600 hr.

YCfor = forecasted Y-POSITION (Centroid), forecasted STORM CENTROID position in the Y-direction from the CORRELATION(Table), in kilometers. Precise to 10^{-4} kilometers.

YCcur = current Y-POSITION (Centroid), the current STORM CENTROID position in the Y-direction from the CORRELATION (Table), in kilometers. Precise to 10^{-4} kilometers.

YS = Y-SPEED (Storm), the speed of a STORM in the Y-direction, in km/hr. Precise to .36 km/hr.

YC = Y-POSITION (Centroid), Y-position of a STORM CENTROID (center of mass), in kilometers. Precise to 10^{-4} kilometers.

YCavg = average Y-POSITION (Centroid), average STORM CENTROID position in the Y-direction from the CORRELATION (Table), in kilometers. Precise to 10^{-4} kilometers.

SS = SPEED (Storm), speed of a STORM, in km/hr. Precise to .36 km/hr.

DS = DIRECTION (Storm), direction from which a STORM is moving, in radians. Precise to 10^{-3} radians.

Note: This algorithm was implemented using 32 bit precision at AFGL.

Note: Precision is to the units specified unless otherwise stated.

3.2.2 SYMBOLIC FORMULAS

COMPUTE (X-SPEED (Storm))

$$XS = [\sum_n (XC_n - XCavg)(TS_n - TSavg)]/[\sum_n (TS_n - TSavg)^2]$$

where n is the number of times used in the forecast for a particular storm.

COMPUTE (Y-SPEED (Storm))

$$YS = [\sum_n (YC_n - YCavg)(TS_n - TSavg)]/[\sum_n (TS_n - TSavg)^2]$$

where n is the number of times used in the forecast for a particular storm.

COMPUTE (FORECAST ERROR)

$$FE = [(XE - XCcur)^2 + (YE - YCcur)^2]^{0.5}$$

where;

$$XE = (XSpre)(TScur - TSpre) + XCpre$$

$$YE = (YSpre)(TScur - TSpre) + YCpre$$

COMPUTE (TRACK VARIANCE (X-direction))

$VX = CVX/(n - 2)$

where;

$$CVX = [\sum_{n} (XC_{n} - XCavg)^{2}] - (XS)^{2}[\sum_{n} (TS_{n} - TSavg)^{2}]$$

COMPUTE (TRACK VARIANCE (Y-direction))

$VY = CVY/(n - 2)$

where;

$$CVY = [\sum_{n} (YC_{n} - YCavg)^{2}] - (YS)^{2}[\sum_{n} (TS_{n} - TSavg)^{2}]$$

COMPUTE (forecasted X-POSITION(Centroid))

$XCfor = XCcur + (XS)(FI)$

COMPUTE (forecasted Y-POSITION(Centroid))

$YCfor = YCcur + (YS)(FI)$

COMPUTE (SPEED (Storm))

$SS = (XS^{2} + YS^{2})^{0.5}$

COMPUTE (DIRECTION (Storm))

$DS = \tan^{-1}(XS/YS) + \pi$

COMPUTE (PERMISSIBLE ERROR)

$PE = (AER)[(EI)/(FI)]$

COMPUTE (mean FORECAST ERROR)

$$FEmean = \sum_{n} FE_{n}/n$$

Note: n under the summation refers to a single storm over its entire life-time.

4.0 OUTPUTS

4.1 IDENTIFICATION

DIRECTION (Storm) is the direction from which a STORM is moving.

A set of ordered pairs of forecasted X-POSITIONs (Centroid) and forecasted Y-POSITIONs (Centroid) of identified storms for the actual forecast time are outputted. In addition to this, a set of FORECAST ERROR values which indicate the error in the variance of the forecasted STORM tracks are outputted.

SPEED (Storm) is a set of values indicating speeds at which the identified storms are travelling.

X-SPEED (Storm) and Y-SPEED (Storm) are sets of the X and Y-component speeds of STORMs.

4.2 DISTRIBUTION

Many of the outputs from this algorithm (forecasted X-POSITION (Centroid), forecasted Y-POSITION (Centroid), FORECAST ERROR, X-SPEED (Storm), and Y-SPEED (Storm)) can be used by a product generation algorithm which will output information concerning expected storm movement. The output will also be used by an error analysis algorithm to verify the forecasts against the actual positions calculated at the verification time.

SPEED(Storm) and DIRECTION(Storm) are intended for input to the STORM STRUCTURE [009] and HAIL [012] algorithms.

SPEED(Storm) is intended for input to the TRANSVERSE WIND [011] algorithm.

5.0 INFERENCES

5.1 LIMITATIONS

This algorithm averages the centroid shifting, or jitter, which occurs in some storms. It handles breakaway storms as new storms and initiates a new track. Because several time steps are used for the forecast, a sudden shift in a centroid location will be damped out until the new track becomes established. If a small number of previously identified storms exist, forecasted speed may be inaccurate.

STORM STRUCTURE

ALGORITHM DESCRIPTION

NX-DR-03-009/44

MAJOR REVISIONS SINCE MAY 1984

Storm Structure (009)

1. All algorithms appearing in the May 1984 report have undergone the following changes:

    a. Editorial and typographical changes.

    b. Explicit declaration of data element precision.

    c. Renaming of data element names and symbols to achieve unique naming.

    d. Data Dictionary changes resulting from other changes.

2. Deleted RADIUS CORRECTION (Earth) from the list of adaptable parameters.

3. WRITE added for MASS (Storm).

1.0 PROLOGUE

1.1 FUNCTIONAL DESCRIPTION

The purpose of this algorithm is to determine the structure of storms (see Figure 1). This structure is determined by first identifying a storm as a three-dimensional region of significant reflectivity values and then determining the following structure parameters:

- o Storm base
- o Storm top
- o Storm volume
- o Maximum storm reflectivity and its altitude of occurrence
- o Maximum storm spectrum width and its altitude of occurrence
- o Maximum storm velocity at the lowest elevation angle
- o Storm tilt and its components along horizontal and vertical axes
- o Storm overhang
- o Overhang orientation

The first step in the procedure is to acquire the parameters from the STORM CENTROIDS [005] algorithm that are necessary inputs for the computation of the STORM STRUCTURE outputs. In the second step, the previously mentioned structure parameters are computed.

1.2 SOURCE

This algorithm has been implemented at AFGL, Sudbury, Massachusetts. It was developed by C. Bjerkaas and modified by P. Petrocchi to include computations of storm overhang and storm tilt.

REFERENCES

Bjerkaas, C.L., and D.E. Forsyth, 1980: An Automated Real-Time Storm Analysis and Storm Tracking Program (WEATRK). AFGL-TR-80-0316, Air Force Geophysics Laboratory, Hanscom AFB, Massachusetts 01731.

Forsyth, D.E., C.L. Bjerkaas, and P.J. Petrocchi, 1981: Modular Radar Analysis Software System (MRASS). Preprints 20th Conference on Radar Meteorology (Boston), Amer. Meteor. SOC., 696-699.

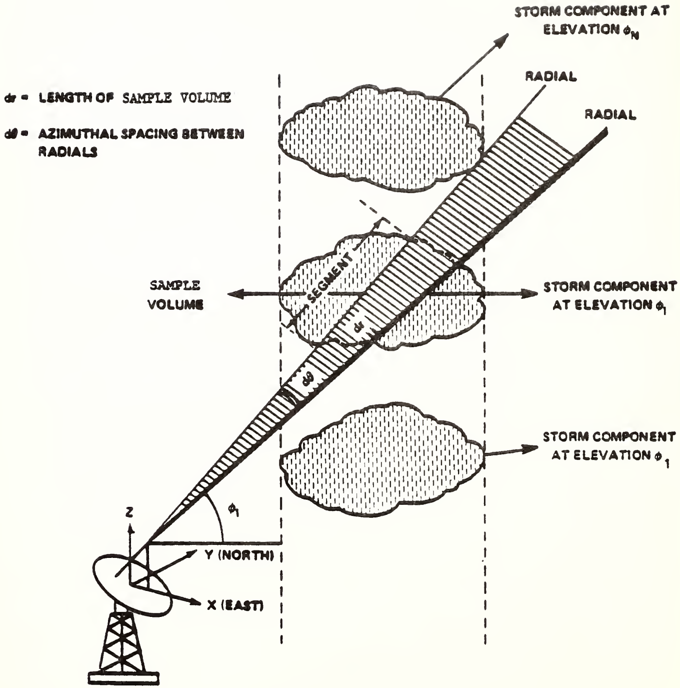

STORM COMPONENT AT ELEVATION ϕ_N
RADIAL
RADIAL
dr = LENGTH OF SAMPLE VOLUME
dθ = AZIMUTHAL SPACING BETWEEN RADIALS
SAMPLE VOLUME
SEGMENT
dr
dθ
STORM COMPONENT AT ELEVATION ϕ_1
STORM COMPONENT AT ELEVATION ϕ_1
ϕ_1
Z
Y (NORTH)
X (EAST)

FIGURE 1. 3D STORM

1.3 PREPROCESSING ENVIRONMENT

The STORM STRUCTURE algorithm has been implemented together with the STORM CENTROIDS [005] algorithm. These data are assumed to be preprocessed for the elimination of bad data (noise) and velocity unfolding in both magnitude and range. The algorithm also relies on output data from a storm forecasting process giving information about the speed and direction of motion of storms of interest. This data comes from the STORM POSITION FORECAST [008] algorithm.

2.0 INPUTS

2.1 IDENTIFICATION

AREA (Storm Component) = Area of a STORM COMPONENT at a particular ELEVATION, in km^2. Precise to 10^{-6} km^2.

DIRECTION(Storm) = Direction from which a STORM is moving, in radians.

ELEVATION = Elevation angle, in radians.

HEIGHT (Storm Component-Centroid) = The height of the centroid of a STORM COMPONENT at a particular ELEVATION above the ground, in kilometers. Precise to 10^{-4} kilometers.

maximum REFLECTIVITY FACTOR(DBZE) = The maximum effective radar reflectivity factor, in dBZe.

maximum SPECTRUM WIDTH = The maximum spectrum width value, in km/hr.

MASS(Storm) = The mass weighted volume of a STORM, in kilograms. Precise to 10^{-3} kilograms.

SPEED (Storm) = Speed of a STORM, in km/hr.

STORM = A three-dimensional region composed of STORM COMPONENTs characterized by reflectivity values above a given threshold, ordered by mass weighted volume.

TIME = The times at which data were collected, in hours.

maximum VELOCITY (Doppler) = Maximum Doppler value, in km/hr.

X-POSITION = X-position of the CENTROID, in kilometers.

Y-POSITION = Y-position of the CENTROID, in kilometers.

2.2 ACQUISITION

ELEVATION is acquired as measured data from the radar's instantaneous position during radial data collection.

SPEED (Storm) and DIRECTION (Storm) are acquired from the STORM POSITION FORECAST [008] algorithm.

TIME is acquired by direct measurement during initial data acquisition.

STORMs, MASS(Storm), maximum REFLECTIVITY FACTOR (DBZE), maximum VELOCITY (Doppler), maximum SPECTRUM WIDTH, AREA (Storm Component), HEIGHT(Storm Component-Centroid), X-POSITION and Y-POSITION are obtained from the STORM CENTROIDS [005] algorithm.

3.0 PROCEDURE

3.1 ALGORITHM

```
BEGIN ALGORITHM (STORM STRUCTURE)

1.0  DO FOR ALL (STORMs)
     1.1  COMPUTE (VOLUME (Storm))
     1.2  COMPUTE (maximum REFLECTIVITY (Storm))
     1.3  COMPUTE (maximum HEIGHT (Storm Reflectivity))
     1.4  COMPUTE (maximum STORM VELOCITY (Lowest Elevation))
     1.5  COMPUTE (maximum STORM SPECTRUM WIDTH)
     1.6  COMPUTE (maximum HEIGHT (Storm Spectrum Width))
     1.7  COMPUTE (STORM BASE)
     1.8  COMPUTE (STORM TOP)
     1.9  IF (STORM TOP was computed at the highest
             ELEVATION)
             THEN (Mark the STORM TOP as unknown)
          END IF
     1.10 COMPUTE (STORM TILT)
     1.11 COMPUTE (STORM X-TILT)
     1.12 COMPUTE (STORM Y-TILT)
     1.13 COMPUTE (STORM OVERHANG)
     1.14 COMPUTE (OVERHANG ORIENTATION)
     1.15 WRITE (STORM BASE)
     1.16 WRITE (STORM TOP)
     1.17 WRITE (VOLUME (Storm))
     1.18 WRITE (maximum REFLECTIVITY (Storm))
     1.19 WRITE (maximum HEIGHT (Storm Reflectivity))
     1.20 WRITE (maximum STORM SPECTRUM WIDTH)
     1.21 WRITE (maximum HEIGHT (Storm Spectrum Width))
     1.22 WRITE (maximum STORM VELOCITY (Lowest Elevation))
     1.23 WRITE (STORM TILT)
     1.24 WRITE (STORM X-TILT)
     1.25 WRITE (STORM Y-TILT)
     1.26 WRITE (STORM OVERHANG)
     1.27 WRITE (OVERHANG ORIENTATION)
     1.28 WRITE (MASS(Storm))
     END DO

END ALGORITHM (STORM STRUCTURE)
```

3.2 COMPUTATION

3.2.1 NOTATION

X = X-POSITION, X-position of the CENTROID, in kilometers. Precise to 10^{-4} kilometers.

i = INDEX (Elevation), the index for ELEVATION.

PHI# = ELEVATION, elevation angle, in radians. Precise to 10^{-3} radians.

PI# = PI, a mathematical constant (3.1416), unitless.

Y = Y-POSITION, Y-position of the CENTROID, in kilometers. Precise to 10^{-4} kilometers.

HSCC = HEIGHT (Storm Component-Centroid), the height of the centroid of a STORM COMPONENT at a particular ELEVATION above the ground, in kilometers. Precise to 10^{-4} kilometers.

RCOE = RADIUS CORRECTION(Earth), the factor by which the RADIUS(Earth) is multiplied to account for refraction of the radar beam (1.21).

RE = RADIUS (Earth), the radius of the Earth (6371), in kilometers. Precise to 10^{-4} kilometers.

A = AREA (Storm Component), area of a STORM COMPONENT at a particular ELEVATION, in km^2. Precise to 10^{-6} km^2.

DBZEmax = maximum REFLECTIVITY FACTOR(DBZE), maximum effective radar reflectivity factor, in dBZe.

VDmax = maximum VELOCITY (Doppler), maximum Doppler velocity value, in km/hr. Precise to .36 km/hr.

Wmax = maximum SPECTRUM WIDTH, the maximum spectrum width value, in km/hr. Precise to .36 km/hr.

VOL = VOLUME (Storm), the volume of a STORM, in km^3.

HSCCdif = difference HEIGHT (Storm Component-Centroid), the height difference between centroids of STORM COMPONENTs at two separate ELEVATIONs, in kilometers. Precise to 10^{-4} kilometers.

ZSmax = maximum REFLECTIVITY (Storm), maximum effective reflectivity value detected among all STORM COMPONENTs of each STORM, in dBZe.

HSZmax = maximum HEIGHT (Storm Reflectivity), the height above the ground where the maximum reflectivity occurs, in kilometers. Precise to 10^{-4} kilometers.

STEmaxlow = maximum STORM VELOCITY (Lowest Elevation), the maximum STORM VELOCITY at the lowest ELEVATION, in km/hr. Precise to .36 km/hr.

SSWmax = maximum STORM SPECTRUM WIDTH, the maximum spectrum width of a STORM, in km/hr. Precise to .36 km/hr.

HWmax = maximum HEIGHT (Storm Spectrum Width), the altitude where maximum spectrum width occurs, in kilometers. Precise to 10^{-4} kilometers.

STB = STORM BASE, the altitude of the base of the STORM (lowest STORM COMPONENT), in kilometers. Precise to 10^{-4} kilometers.

Xlow = lowest X-POSITION, X-position of the center of mass of the STORM COMPONENT at the lowest ELEVATION, in kilometers. Precise to 10^{-4} kilometers.

Ylow = lowest Y-POSITION, Y-position of the center of mass of the STORM COMPONENT at the lowest ELEVATION, in kilometers. Precise to 10^{-4} kilometers.

STT = STORM TOP, the height above the ground of the centroid of highest STORM COMPONENT, in kilometers. Precise to 10^{-4} kilometers.

Xhgh = highest X-POSITION, X-position of the center of mass of the STORM COMPONENT of the same STORM at the highest ELEVATION, in kilometers. Precise to 10^{-4} kilometers.

Yhgh = highest Y-POSITION, Y-position of the center of mass of the STORM COMPONENT of the same STORM at the highest ELEVATION, in kilometers. Precise to 10^{-4} kilometers.

STI = STORM TILT, the angle (with respect to the Z-axis) between the centroid position of the STORM COMPONENT at the lowest ELEVATION and another STORM COMPONENT within the same storm, in radians. Precise to 1.75×10^{-4} radians.

Xfor = forecasted X-POSITION, the forecasted X-position of the CENTROID, in kilometers. Precise to 10^{-4} kilometers.

Yfor = forecasted Y-POSITION, the forecasted Y-position of the CENTROID, in kilometers. Precise to 10^{-4} kilometers.

DS = DIRECTION (Storm), direction from which a STORM is moving, in radians. Precise to 10^{-3} radians.

SS = SPEED (Storm), speed of a STORM, in km/hr. Precise to .36 km/hr.

T = TIME, the times at which data were collected, in hours. Precise to 1/3600 hr.

STX = STORM (X-Tilt), storm tilt along the X-axis between the centers of mass of STORM COMPONENTs at different ELEVATIONs, in radians. Precise to 10^{-3} radians.

STY = STORM (Y-Tilt), storm tilt along the Y-axis between the centers of mass of STORM COMPONENTs at different ELEVATIONs, in radians. Precise to 10^{-3} radians.

OVH = STORM OVERHANG, the distance between the edge of the STORM COMPONENT at a particular ELEVATION and the centroid of another STORM COMPONENT of the same storm at the lowest ELEVATION, in kilometers. Precise to 10^{-4} kilometers.

OVO = OVERHANG ORIENTATION, the overhang orientation between the edge of the STORM COMPONENT at a particular ELEVATION and the centroid of the STORM COMPONENT of the same storm at the lowest ELEVATION, in radians. Precise to 10^{-3} radians.

MST = MASS(Storm), the mass weighted volume of a STORM, in kilograms. Precise to 10^{-3} kilograms.

Note: Precision is to units specified unless otherwise stated.

3.2.2 SYMBOLIC FORMULAS

COMPUTE (VOLUME (Storm))

$$VOL_n = \sum_i (A_i)\ (HSCCdif_{i(i+1)})$$

where,

$$HSCCdif_{i(i+1)} = [(X_i^2 + Y_i^2)^{1/2}](\sin d\phi)/(\cos \phi_i)$$

$$d\phi = (\phi_{i+1} - \phi_{i-1})/2$$

COMPUTE (maximum REFLECTIVITY (Storm))

$ZSmax = DBZEmax_i$ if $DBZEmax_i > ZSmax$

COMPUTE (maximum HEIGHT (Storm Reflectivity))

$HSZmax = HSCC_i$ if $DBZEmax_i = ZSmax$

COMPUTE (maximum STORM VELOCITY (Lowest Elevation))

STEmaxlow = Maximum $|VDmax_i|$ where i corresponds to the lowest elevation angle contained in a STORM.

COMPUTE (maximum STORM SPECTRUM WIDTH)

$SSWmax = Wmax_i$ if $Wmax_i > SSWmax$

COMPUTE (maximum HEIGHT (Storm Spectrum Width))

$HWmax = HSCC_i$ if $Wmax_i = SSWmax$

COMPUTE (STORM BASE)

$$STB = \{(Xlow^2 + Ylow^2)/(\cos^2\phi)/[2(RCOE)(RE)]\} + (Xlow^2 + Ylow^2)^{1/2}(\tan \phi)$$

COMPUTE (STORM TOP)

$$STT = \{[(Xhgh^2 + Yhgh^2)/(\cos^2\phi)/[2(RCOE)(RE)]\} + (Xhgh^2 + Yhgh^2)^{1/2}\ (\tan \phi)$$

COMPUTE (STORM TILT)

$$STI = \tan^{-1}\{[(Xfor_{i+n} - X_i^2) + (Yfor_{i+n} -$$
$$Y_i)^2]^{1/2}/(HSCC_{i+n}-HSCC_i)\}$$

where,

$$Xfor_{i+n} = X_{i+n} - [-\sin(DS)(SS)(T_{i+n} - T_i)]$$

$$Yfor_{i+n} = Y_{i+n} - [-\cos(DS)(SS)(T_{i+n} - T_i)]$$

and n is the number of elevations above the lowest STORM COMPONENT elevation i.

COMPUTE (STORM X-TILT)

$$STX = \tan^{-1} (|Xfor_{i+n} - X_i|/HSCC_{i+n}-HSCC_i)$$

where $Xfor_{i+n}$ is as defined above.

COMPUTE (STORM Y-TILT)

$$STY = \tan^{-1} (|Yfor_{i+n} - Y_i|/HSCC_{i+n}-HSCC_i)$$

where $Yfor_{i+n}$ is as defined above.

COMPUTE (STORM OVERHANG)

$$OVH = [(Xfor_{i+n} - X_i)^2 + (Yfor_{i+n} - Y_i)^2]^{1/2} +$$
$$(A_{i+n}/\pi)^{1/2} - (A_i/\pi)^{1/2}$$

where $Xfor_{i+n}$ is defined above and n is the number of elevations above the lowest STORM COMPONENT elevation i.

COMPUTE (OVERHANG ORIENTATION)

$$OVO = \tan^{-1}[(Xfor_{i+n} - X)/(Yfor_{i+n} - Y_i)]$$

where $Xfor_{i+n}$ and $Yfor_{i+n}$ are defined above.

4.0 OUTPUTS

4.1 IDENTIFICATION

X-POSITION, Y-POSITION, maximum REFLECTIVITY FACTOR(DBZE), STORM BASE, MASS(Storm), STORM TOP, VOLUME (Storm), maximum REFLECTIVITY (Storm), maximum HEIGHT (Storm Reflectivity), maximum STORM SPECTRUM WIDTH, maximum HEIGHT (Storm Spectrum Width), maximum STORM VELOCITY (Lowest Elevation), STORM TILT, STORM X-Tilt, STORM Y-Tilt, STORM OVERHANG and OVERHANG ORIENTATION are the outputs for each identified storm.

4.2 DISTRIBUTION

The outputs of this algorithm are used to describe the structure of identified storms which, in turn, may be used by special meteorological analysis algorithms for detecting severe weather phenomena, e.g., hail. The outputs can be used by the HAIL [012] algorithm.

5.0 INFERENCES

5.1 LIMITATIONS

The algorithm is limited by the quality of the input data. If noise spikes exist, the reflectivity and velocity data will be biased, leading to incorrect structure identification.

The assumption that storm components are circular in the overhang computation may cause the actual amount of overhang to be inaccurately estimated. The extent of this uncertainty is not known at this time.

Storm tilt errors increase with range and with less elevation angle increments. At near ranges it is possible for a storm component at a lower elevation angle to have a greater height than a component at a higher elevation angle. Storm overhang may be computed incorrectly due to poor forecasted storm speeds.

TRANSVERSE WIND

ALGORITHM DESCRIPTION

NX-DR-03-011/27

MAJOR REVISIONS SINCE MAY 1984

Transverse Wind (011)

1. All algorithms appearing in the May 1984 report have undergone the following changes:

    a. Editorial and typographical changes.

    b. Explicit declaration of data element precision.

    c. Renaming of data element names and symbols to achieve unique naming.

    d. Data Dictionary changes resulting from other changes.

2. Scalar averaging of wind has been replaced by vector averaging.

1.0 PROLOGUE

1.1 FUNCTIONAL DESCRIPTION

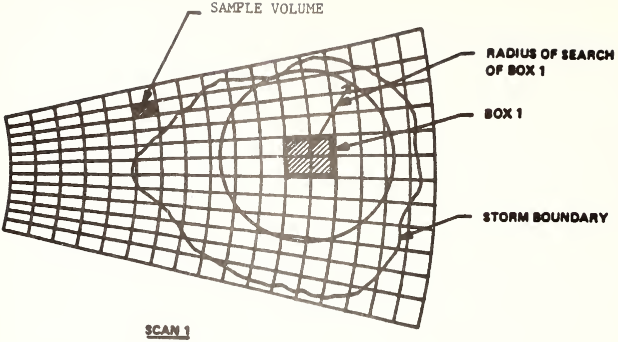
The TRANSVERSE WIND algorithm may determine horizontal wind speed and direction by seeking similar patterns in two fields of radar reflectivity. These fields are scans collected at the same elevation(i.e., 0.4°-0.8°) and retained on polar axes.

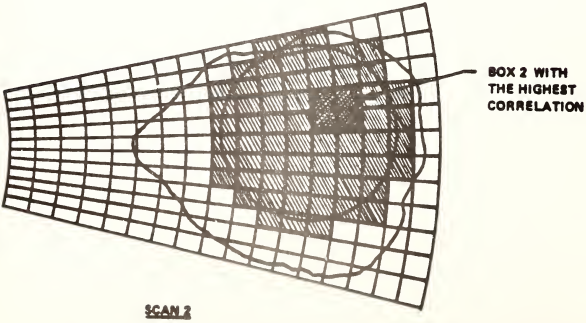
Arrays of azimuthal and range points are identified as the resolution size for correlation between the scans. Such an array is termed a "BOX". The size of the BOX is adjustable and has an equal number of sample volumes in range and azimuth (see Figure 1.0).

A sector within a scan is selected to have outer boundaries enclosing a storm of interest. The sector in the first scan is partitioned into BOXes, e.g., BOX(1)s. These BOX(1)s overlap each other by a specified percentage, which is partially dependent on BOX size. A radius of search is identified around each BOX(1). This radius is calculated by multiplying the time lag between scans by the storm velocity (from the STORM POSITION FORECAST [008] algorithm). If this velocity is not available the value is set to 30m/s. This value may, however, be increased or decreased depending on individual storm motion.

A BOX from the first scan is compared with all BOXes of the same size from the second scan, e.g., BOX(2)s whose centers fall within the radius of search. The BOX(2)s are determined by all combinations of BOXes offset by one sample volume in range and/or azimuth. Correlation coefficients with each BOX(2) are calculated using the range and azimuth data points and the BOX(2) with the highest correlation is identified. To improve the resolution of the correlation, the correlation coefficient values around the highest correlation coefficient are fit with a second order curve in range and again in azimuth. The second order fits are solved to find the range and azimuth of the peak value, which is identified as the optimum correlation coefficient (see Figure 2.0). The location (center) of the BOX(1) from the first scan and the location of the optimum correlation coefficient from the second scan are converted from polar coordinates to rectangular coordinates. A velocity vector is formed by dividing the distance between the geometric center of the BOX(1) from the first scan and the location of the optimum correlation coefficient location from the second scan by the time interval between scans.

The next BOX(1) from the first scan, which may overlap the previous BOX(1) by a specific percentage, is then selected.





SHADED AREA ENCLOSES ALL BOX 2's WHOSE CENTERS FALL WITHIN THE RADIUS OF SEARCH.

Figure 1.0. Determination of BOX 2 With Highest Correlation to BOX 1.

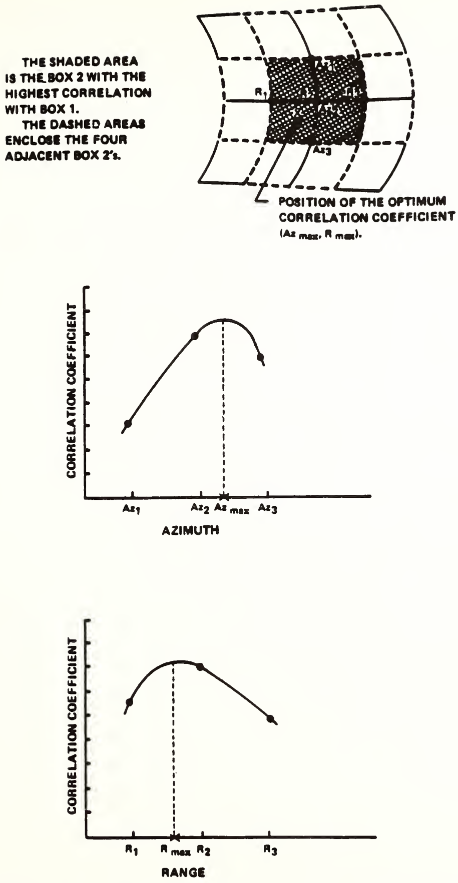

THE SHADED AREA IS THE BOX 2 WITH THE HIGHEST CORRELATION WITH BOX 1.
THE DASHED AREAS ENCLOSE THE FOUR ADJACENT BOX 2's.
R_1
Az_3
POSITION OF THE OPTIMUM CORRELATION COEFFICIENT (Az_{max}, R_{max}).
CORRELATION COEFFICIENT
Az_1
Az_2
Az_{max}
Az_3
AZIMUTH
CORRELATION COEFFICIENT
R_1
R_{max}
R_2
R_3
RANGE

Figure 2.0. Determination of the Optimum Correlation Coefficient Position Using Second Order Polynomials

The new BOX(1) is then used to calculate correlation coefficients with all BOX(2)s within its radius of search. This process continues until all the vectors throughout the sector covering the storm of interest are calculated.

1.2 SOURCE

The original research on detection of internal storm motions using this pattern recognition technique was done by Dr. Ron Rinehart as a Ph.D. dissertation at Colorado State University in 1979. The algorithm was originally written by Ellen Garvey and modified by John Tuttle of the National Center for Atmospheric Research. This version of the algorithm was developed by Said Hamidi of Systems and Applied Sciences Corporation (SASC) working for the NEXRAD Interim Operational Test Facility (IOTF) at the National Severe Storms Laboratory (NSSL).

REFERENCES

Hamidi, Said, R.E. Rinehart, and John Tuttle, 1983: Test of a Transverse Wind Algorithm for NEXRAD in Real-Time. Preprints, 21st Conference on Radar Meteorology (Edmonton, Alberta, Canada), AMS, Boston.

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1.3 PROCESSING ENVIRONMENT

This algorithm uses the radar reflectivity data obtained by a radar. If the data is contaminated with ground clutter, preprocessing is required for the elimination of the ground clutter and point targets.

2.0 INPUTS

2.1 INDENTIFICATION

AZIMUTH = Azimuthal position, in radians.

BOX = A window comprised of an equal number of SAMPLE VOLUMES in range and azimuth defining the size of the area to be correlated.

ELEVATION = Elevation angle, in radians.

BOX OVERLAP = Percent overlap desired from the initial box in the first scan to the second box in the second scan. Overlap values can range from just greater than zero to just under 100%.

SECTOR (Transverse Wind) = Reflectivity values from a subset of a radar scan determined by a minimum and maximum range, and minimum and maximum azimuth, in radians.

REFLECTIVITY FACTOR (DBZE) = The effective radar reflectivity factor of a SAMPLE VOLUME, in dBZe.

RANGE (Slant) = The slant range to the center of a SAMPLE VOLUME, in kilometers.

SPEED (Storm) = Speed of a storm, in km/hr.

TIME (Scan) = The beginning time of a scan, in hours.

2.2 ACQUISITION

AZIMUTH, ELEVATION, and RANGE (Slant) are obtained by direct measurement from the radar.

A BOX is a system adaptation parameter.

BOX OVERLAP is a system adaptation parameter. (see Rinehart, 1979; Hamidi et.al., 1983).

REFLECTIVITY Factor (DBZE) is acquired by the radar.

A SECTOR (Transverse Wind) is obtained from the elevation scan.

SPEED (Storm) is obtained from STORM POSITION FORECAST [008] algorithm.

TIME (Scan) is acquired by direct measurement.

3.0 PROCEDURE

3.1 ALGORITHM

```
BEGIN ALGORITHM (TRANSVERSE WIND)

1.0  COMPUTE (TIME (Scan) difference)

2.0  Partition SECTOR (Transverse Wind) from previous radar
     scan into boxes (BOX(1)s), where boxes overlap each
     other by BOX OVERLAP.

3.0  COMPUTE (NUMBER OF POINTS (Box))

4.0  DO FOR ALL (BOX(1)s)
     4.1  COMPUTE (RADIUS (Search))
     4.2  COMPUTE (POSITION (BOX(1)))
     4.3  Identify all BOX(2)s (in the latter scan) which
          are offset by one sample volume from each other
          and are within the RADIUS (Search).
     4.4  DO FOR ALL (BOX(2)s)
             COMPUTE (CORRELATION (Coefficient))
          END DO
     4.5  Find BOX(2) with highest CORRELATION
          (Coefficient) and its corresponding range and
          azimuth.
     4.6  Select highest CORRELATION (Coefficient) and
          two neighboring CORRELATION (Coefficients) in
          both range and azimuth.
     4.7  COMPUTE (SECOND-ORDER FIT)
     4.8  COMPUTE (POSITION (Optimum Correlation
                  Coefficient))
     4.9  COMPUTE ((X-POSITION Box) optimum)
     4.10 COMPUTE ((Y-POSITION Box) optimum)
     4.11 COMPUTE (U Wind component)
     4.12 COMPUTE (V Wind Component)
     4.13 COMPUTE (SPEED (Horizontal Wind))
     4.14 COMPUTE (DIRECTION (Wind))
     4.15 Identify SPEED (Horizontal Wind) and
          DIRECTION (Wind) as a VECTOR.
     4.16 WRITE (VECTOR)
     END DO

5.0  COMPUTE (average U and V wind component)

6.0  COMPUTE (average SPEED (Horizontal Wind))

7.0  COMPUTE (average DIRECTION (Wind))

8.0  WRITE (average SPEED (Horizontal Wind))

9.0  WRITE (average DIRECTION (Wind))

10.0 WRITE (NUMBER OF POINTS (Box))

END ALGORITHM (TRANSVERSE WIND)
```

3.2 COMPUTATION

3.2.1 NOTATION

TSdif = TIME (Scan) difference, time difference between scans, in hours.

Tcur = Current TIME, the current time at which data is collected, in hours.

Tpre = Previous TIME, the previous time at which data was collected, in hours.

NOP = NUMBER OF POINTS (Box), the number of reflectivity points in a BOX.

RDS = RADIUS (Search), the maximum distance the first BOX can search, in kilometers.

SS = SPEED (Storm), speed of a storm, in km/hr.

PB = POSITION (Box), an ordered pair of X and Y coordinates identifying the center of a BOX1, in km.

POC = POSITION (Optimum Correlation Coefficient), an ordered pair of range and azimuth points identifying the position of the optimum correlation coefficient, in kilometers and radians respectively.

SOF = SECOND-ORDER FIT, curves fit to range and azimuth data to determine the optimum correlation coefficient location using second-order polynomials.

XB = X-POSITION (Box), X-position of a BOX(1) center, in kilometers.

YB = Y-POSITION (Box), Y-position of a BOX(1) center, in kilometers.

RS = RANGE (Slant), the slant range to the center of a SAMPLE VOLUME, in kilometers.

AZ = AZIMUTH, azimuthal position, in radians. Precise to 10^{-3} radians.

BOX(1) = BOX(1), a window comprised of an equal number of SAMPLE VOLUMES in range and azimuth defining the size of the area to be correlated, taken from the first scan.

BOX(2) = BOX(2), a window comprised of an equal number of SAMPLE VOLUMES in range and azimuth defining the size of the area to be correlated, taken from the second scan.

PHI# = ELEVATION, elevation angle, in radians. Precise to 10^{-3} radians.

CC = CORRELATION (Coefficient), a number representing the degree to which two variables are dependent upon each other.

VNSavg = average VELOCITY (North-South), the average north-south component of the horizontal wind in a sector, in km/hr.

TBO = BOX OVERLAP, percent overlap desired from the initial box in the first scan to the next box in the second scan.

DBZE(1) = first-scan REFLECTIVITY FACTOR (DBZE), first-scan effective radar reflectivity factor of a data SAMPLE VOLUME, in dBZe.

DBZE(2) = second-scan REFLECTIVITY FACTOR (DBZE), second-scan effective radar reflectivity factor of a data SAMPLE VOLUME, in dBZe.

VEC = VECTOR, indicates wind direction and speed. Wind Speed is in km/hr and direction is in radians.

VEW = VELOCITY (East-West), the u (east-west) component of the wind speed, in km/hr.

VNS = VELOCITY (North-South), the v (north-south) component of the wind speed, in km/hr.

VEWavg = average VELOCITY (East-West), the average east-west component of the horizontal wind in a sector, in km/hr.

CCopt = Optimum CORRELATION (Coefficient), a number representing the optimum degree to which two variables are dependent upon each other.

CR1, CR2, CR3 = Coefficients of a second-order equation for the correlation coefficient as a function of range. Coefficients' units are unitless, 1/km and $1/km^2$ respectively.

CA1, CA2, CA3 = Coefficients of a second-order equation for the correlation coefficient as a function of azimuth. Coefficients' units are unitless, 1/radians and $1/radians^2$ respectively.

Xopt, Yopt = Optimum X-POSITION, Optimum Y-POSITION, the X and Y-positions of the optimum correlation coefficient value of a BOX, in kilometers.

SHW = SPEED (Horizontal Wind), horizontal wind speed, in km/hr.

DW = DIRECTION (Wind), the horizontal direction from which the wind is flowing, in radians. Precise to 10^{-3} radians.

SHWavg = Average SPEED (Horizontal Wind), the average horizontal wind speed, in km/hr.

DWavg = Average DIRECTION (Horizontal Wind), the average direction from which the wind is flowing, in radians. Precise to 10^{-3} radians.

k = INDEX (Slant Range), the index for RANGE (Slant).

j = INDEX (Azimuth), the index for AZIMUTH.

Note: Precision is equivalent to the units unless otherwise stated.

3.2.2 SYMBOLIC FORMULAS

COMPUTE (Time (Scan) difference)

TSdif = Tcur - Tpre

COMPUTE (NUMBER OF POINTS (Box))

NOP = (n) (m)

where n is the number of azimuth values and m is the number of range cells (bins) in a BOX.

COMPUTE (RADIUS (Search))

RDS = (SS) (TSdif)

COMPUTE PB (POSITION (BOX(1)))

XB = (RS) (sin(AZ)) (cos(ϕ))

YB = (RS) (cos(AZ)) (cos(ϕ))

COMPUTE (CORRELATION (Coefficient))

$$CC = \frac{\sum_n DBZE(1)_n\ DBZE(2)_n - \frac{1}{n} \sum_n DBZE(1)_n \sum_n DBZE(2)_n}{\left[\sum_n (DBZE(1)_n^2 - n\overline{DBZE}(1)^2) \quad \sum_n (DBZE(2)_n^2 - n\overline{DBZE}(2)^2) \right]^{1/2}}$$

where,

$$(\overline{DBZE}(1))^2 = \left(\sum_n \frac{DBZE(1)_n}{n} \right)^2$$

$$(\overline{DBZE}(2))^2 = \left(\sum_n \frac{DBZE(2)_n}{n} \right)^2$$

and n = NOP

COMPUTE SOF (SECOND-ORDER FIT)

Solve for coefficients:

$$CC_k = CR1 + (CR2)(RS_k) + (CR3)(RS_k)^2$$

$$CC_j = CA1 + (CA2)(AZ_j) + (CA3)(AZ_j)^2$$

where,

k = j = 1, 2, 3, as shown in Figure 2.0.

COMPUTE POC (POSITION (Optimum Correlation Coefficient))

$$\text{RSmax} = \frac{-\text{CR2}}{2(\text{CR3})} \quad ; \quad \frac{d\ \text{CCopt}}{d\ \text{RS}} = 0$$

$$\text{AZmax} = \frac{-\text{CA2}}{2(\text{CA3})} \quad ; \quad \frac{d\ \text{CCopt}}{d\ \text{AZ}} = 0$$

COMPUTE ((X-POSITION) optimum)

$\text{Xopt} = (\text{RSmax})\ (\sin(\text{AZmax}))\ (\cos\ (\phi))$

COMPUTE ((Y-POSITION) optimum)

$\text{Yopt} = (\text{RSmax})\ (\cos(\text{AZmax}))\ (\cos\ (\phi))$

COMPUTE VELOCITY (East-West)

$\text{VEW} = (\text{Xopt} - \text{XB})/\text{TSdif}$

COMPUTE VELOCITY (North-South)

$\text{VNS} = (\text{Yopt} - \text{YB})/\text{TSdif}$

COMPUTE SPEED (Horizontal Wind)

$\text{SHW} = (\text{VEW}^2 + \text{VNS}^2)^{1/2}$

COMPUTE DIRECTION (Wind)

$\text{DW} = (\text{Tan}^{-1})\ \frac{\text{VEW}}{\text{VNS}}$

COMPUTE average wind components

$$\text{VEWavg} = \frac{\sum_n \text{VEW}_n}{n}$$

$$\text{VNSavg} = \frac{\sum_n \text{VNS}_n}{n}$$

where n is the number of vectors in a sector

COMPUTE average SPEED (Horizontal Wind)

$$\text{SHWavg} = \left[(\text{VEWavg}^2 + \text{VNSavg}^2)\right]^{1/2}$$

COMPUTE average DIRECTION (Wind)

$$\text{DWavg} = \text{Tan}^{-1}\ \left(\frac{\text{VEWavg}}{\text{VNSavg}}\right)$$

4.0 OUTPUTS

4.1 IDENTIFICATION

A set of VECTORs each indicating SPEED (Horizontal Wind) and direction (Wind) within the SECTOR.

The average SPEED (Horizontal Wind) and average DIRECTION (Wind) for the SECTOR.

4.2 DISTRIBUTION

The output from the TRANSVERSE WIND algorithm could be displayed as a product.

5.0 INFERENCES

5.1 LIMITATIONS

Precipitation particles tend to move horizontally and vertically (somewhat) with the wind. If they could be tracked, their motion would provide a reliable estimate of the wind field. Instead of tracking precipitation sized particles, the transverse wind algorithm tracks patterns in the reflectivity field. These small scale reflectivity features (i.e., substorm-scale features) do not necessarily move with the winds at the height at which they are observed, thus limiting the usefulness of this algorithm.

The transverse wind algorithm does not consider storm evolution (e.g., growth and decay of individual cells).

Large errors in speed and direction may be introduced when the distances moved by the substorm features are small relative to the data resolution.

The BOX size can vary from very small to very large. But in practice, the size would probably range from 4 km x 4 km to 50 km x 50 km. However, an "optimum" array size exists between the two scans. The time between scans, as well as the resolution volume size, must be known ahead of time to select the best BOX size.

5.2 FUTURE DEVELOPMENTS

Examination of less range resolution (i.e., skipping range gates) for faster processing time.

Study the information that could be gained by combining the radial velocity with the velocity field derived from Transverse Wind Algorithm.

HAIL

ALGORITHM DESCRIPTION

NX-DR-03-012/35

MAJOR REVISIONS SINCE MAY 1984

HAIL (012)

1. All algorithms appearing in the May 1984 report have undergone the following changes:

    a. Editorial and typographical changes.

    b. Explicit declaration of data element precision.

    c. Renaming of data element names and symbols to achieve unique naming.

    d. Data Dictionary changes resulting from other changes.

2. The compute for ANGLE (between Overhang and DIRECTION) was corrected.

3. The following WRITEs were deleted: RADIUS (Storm Component), RANGE (Slant Storm Component), HEIGHT (Storm Component-Centroid), X-POSITION displacement, Y-POSITION displacement, ANGLE (Between Overhang and Direction), DISTANCE (Between Centroids), STORM OVERHANG, DISTANCE (Storm Top and Mid Level) and WEIGHT (Probable).

4. The following WRITEs were added: average SPEED (Storm), average DIRECTION (Storm), WEIGHTS (Positive), WEIGHTS (Probable), Confidence Factor and SCORE.

1.0 PROLOGUE

1.1 FUNCTIONAL DESCRIPTION

The purpose of this algorithm is to identify one of the following four cases:

- a given storm is producing or soon will produce hail
- a given storm is probably producing or will probably produce hail
- a given storm is not currently producing hail
- a given storm cannot be analyzed due to lack of sufficient data.

This algorithm analyzes storm data available in a specific format as described by the following: A storm is defined as a three-dimensional region of significant reflectivity values above a specified threshold. It is assumed to be made up of two-dimensional, circular storm components occurring at different elevation angles of radar observation. A storm component has associated with it a centroid, a maximum reflectivity value, and an area. The centroid is represented in a Cartesian coordinate system with the radar at the origin. The X-axis denotes east-west directions and the Y-axis denotes north-south directions. The maximum reflectivity value in a storm component is defined as the largest value of reflectivity obtained from the radar for the resolution volumes within the identified storm component. The area of a storm component is defined as the area of the circle representing the actual storm component. The centroid, the maximum reflectivity and the area for each storm component within a storm are obtained (refer to STORM STRUCTURE [009]) as inputs to this algorithm. Additional storm parameters will be used as prime inputs. These are the estimated speed and direction of storm movement, the maximum reflectivity value within a whole storm, and the height of the storm's highest detectable storm component.

Definitions of two terms are necessary to understand the process of analyzing the storm data: overhang and tilt. A storm is said to have an overhang if the edge of the storm component at a height between specified heights extends beyond the edge of a storm component at the lowest elevation by a specified distance. A storm is said to have a tilt if a line connecting the centroid of a midlevel storm component to the centroid of the lowest storm component is to the right or rear of the direction of the movement of that storm.

Seven hail identifiers are used to determine the current hail producing state of the storm. A weight is associated with each identifier based on the empirical study of storms at AFGL. The identifiers and their weights are:

#1 The highest detectable storm component is at least 8 km. [WEIGHT = HW1]

#2 The maximum reflectivity value within a storm is greater than 55 dBZe. [WEIGHT = HW2]

#3 The centroid of the lowest level storm component is to the north of a centroid at any higher level. [WEIGHT = HW3]

#4 The direction of tilt is between 45 and 180 degrees to the right of the direction of storm movement. [WEIGHT = HW4]

#5 The maximum reflectivity in a storm component at midlevels (i.e., 5 to 12 km heights) is at least 50 dBZe. [WEIGHT = HW5]

#6 The overhang at the midlevel extends to at least 4 km beyond a lower level storm component. [WEIGHT = HW6]

#7 The highest elevation storm component exists above a midlevel overhang. [WEIGHT = HW7]

The above identifiers can be identified in two ways. A _positive_ identification occurs when sufficient data exists to test for the presence of the corresponding condition associated with the identifier. A _probable_ identification occurs when sufficient data does not exist (e.g., the radar could not take measurements beyond a fixed elevation angle). The algorithm tests for these two types of conditions and then computes two sums, one using only positive identifiers and another using only probable identifiers. The decision of labelling a storm as positively, probably, or not hail producing, or if storm data is insufficient for hail analysis is then made as indicated by the procedure section.

For any given storm, when a positive hail identifier is found, there is no need to continue identifying the same identifier, i.e., the test need only pass once.

1.2 SOURCE

This algorithm has been implemented by Air Force personnel at the Air Force Geophysics Laboratory (AFGL), Sudbury, Massachusetts.

REFERENCES

Forsyth, D.E., C.L. Bjerkaas, and P.J. Petrocchi, 1981: Modular Radar Analysis Software System (MRASS). _Preprints, 20th Conference on Radar Meteorology_ (Boston), Amer. Meteor. Soc., 696-699.

1.3 PROCESSING ENVIRONMENT

The HAIL algorithm is implemented as one of six special analysis modules that operate under the Modular Radar Analysis Software System (MRASS) (see reference in Section 1.2) implemented at AFGL, Sudbury. The algorithm requires outputs from the modules implementing algorithms described in STORM CENTROIDS [005], STORM POSITION FORECAST [008], STORM STRUCTURE [009], STORM SEGMENTS [022] and STORM TRACKING [004].

2.0 INPUTS

2.1 IDENTIFICATION

AREA (Storm Component) = Area of a STORM COMPONENT at a particular ELEVATION, in km^2.

DEFAULT (Direction) = A default storm direction value used if directions are not known, in radians.

DEFAULT (Speed) = A default storm speed value used if speeds are not known, in km/hr.

DIRECTION (Storm) = Direction from which the nth STORM is moving, in radians. If the direction is not determined by the STORM POSITION FORECAST [008] algorithm, then its value is set as being unknown.

ELEVATION = Elevation angle, in radians.

maximum REFLECTIVITY (Storm) = Maximum effective reflectivity value detected among all STORM COMPONENTs of each STORM, in dBZe.

SPEED (Storm) = Speed of a storm, in km/hr. If the speed is not determined by the STORM POSITION FORECAST [008] algorithm, then its value is set as unknown.

STORM = A three-dimensional region composed of STORM COMPONENTs characterized by reflectivity values above a given threshold, ordered by mass-weighted volume.

STORM COMPONENT = A group of SAMPLE VOLUMES, contiguous with respect to range (STORM SEGMENTs) and azimuth, at the same elevation angle. More than one may exist at a given elevation.

RADIUS CORRECTION (Earth) = The factor by which the RADIUS (Earth) is multiplied to account for refraction of the radar beam (1.21).

REFLECTIVITY(Storm Component) = Effective reflectivity value detected in an individual STORM COMPONENT, in dBZe.

maximum REFLECTIVITY (Storm Component) = Maximum effective reflectivity value detected in an individual STORM COMPONENT, in dBZe.

STORM TOP = The height above the ground of the centroid of the highest STORM COMPONENT, in kilometers.

THRESHOLD (Direction Angle) = The maximum acceptable deviation of a STORM direction compared to the average direction of all STORMs (1.57), in radians.

HAIL IDENTIFIERS = Seven weighted predictors used to determine probability of hail production by a STORM.

THRESHOLD (Hail #1) = The minimum STORM TOP height to identify HAIL IDENTIFIER #1 (8), in kilometers.

THRESHOLD (Hail #2) = The minimum maximum REFLECTIVITY (Storm) to identify HAIL IDENTIFIER #2 (55), in dBZe.

THRESHOLD (Hail #4) = The angle between the overhang and the direction to identify HAIL IDENTIFIER #4 (.785 through 3.14), in radians.

THRESHOLD (Hail Height) = The height of a mid-level STORM COMPONENT, used to identify HAIL IDENTIFIERS #3, #4, #5 and #6 (5-12), in kilometers.

THRESHOLD (Hail #5) = The minimum REFLECTIVITY (Storm Component) used to identify HAIL IDENTIFIER #5 (50), in dBZe.

THRESHOLD (Hail Low) = The maximum height of the lowest elevation STORM COMPONENT, used to identify HAIL IDENTIFIER #3, #4 and #6 (5), in kilometers.

THRESHOLD (Hail #6) = The mininum STORM OVERHANG used to identify HAIL IDENTIFIER #6 (4), in kilometers.

THRESHOLD (Hail High Low) = The maximum height of the centroid of the STORM COMPONENT, used to identify HAIL IDENTIFIERs #2, #3 and #4 (5), in kilometers.

THRESHOLD (Low Confidence) = The minimum CONFIDENCE FACTOR to compute a SCORE (25).

THRESHOLD (Score) = The maximum value below which a STORM is labelled to be a non-hail producer (50).

THRESHOLD (High Score) = The minimum score value to label a hail producer (60).

THRESHOLD (High Confidence) = The minimum value to label a STORM as a hail producer (50).

THRESHOLD (High Reflectivity) = The maximum REFLECTIVITY FACTOR(DBZE) above which the STORM is labelled to be a probable hail producer (70), in dBZe.

TIME (Scan) = The beginning time of a scan, in hours.

X-POSITION = X-position of the CENTROID, in kilometers.

Y-POSITION = Y-position of the CENTROID, in kilometers.

WEIGHT = Weight factor (HW1, ..., HW7) associated with each of the HAIL IDENTIFIERS (HW1 = 17, HW2 = 15, HW3 = 7, HW4 = 8, HW5 = 20, HW6 = 15, HW7 = 18).

2.2 ACQUISITION

STORM TOP and maximum REFLECTIVITY(Storm) are acquired as output from the STORM STRUCTURE [009] Algorithm.

ELEVATION and TIME(Scan) are acquired directly as measured values from the Doppler radar.

SPEED(Storm) and DIRECTIOn(Storm) are acquired as outputs from the STORM POSITION FORECAST [008] Algorithm.

X-POSITION, Y-POSITION, STORM COMPONENT, maximum REFLECTIVITY (Storm Component), REFLECTIVITY (Storm Component), STORMs, and AREA(Storm Component) are acquired as outputs from the STORM CENTROIDS [005].

WEIGHT is a set of site dependent system supplied parameters whose value is based on the study of hail producing storms.

All of the adaptable thresholds, DEFAULT(Direction) and DEFAULT (Speed) are site selective parameters. (See Adjustable Parameter Table Appendix C.)

3.0 PROCEDURE

3.1 ALGORITHM

```
BEGIN ALGORITHM (HAIL)

1.0  IF (Current scan is the first scan in which STORMs are
        observed)
        THEN (Set average SPEED (Storm) to DEFAULT (Speed)
             and average DIRECTION (Storm) to DEFAULT
             (Direction))
     END IF

2.0   DO FOR ALL (STORMs)
        IF (SPEED (Storm) is known)
          THEN COMPUTE (X-SPEED (Storm))
               COMPUTE (Y-SPEED (Storm))
        END IF
      END DO

3.0   COMPUTE (average SPEED (Storm))
      WRITE (average SPEED (Storm))

4.0   COMPUTE (average DIRECTION (Storm))
      WRITE (average DIRECTION (Storm))

5.0   DO FOR ALL (STORMs)
     5.1  IF (SPEED (Storm) is unknown)
             THEN (Set SPEED (Storm) to average SPEED
                  (Storm))
          END IF
     5.2  IF (DIRECTION (Storm) is unknown OR DIRECTION
             (Storm) differs from the average DIRECTION
             (Storm) by THRESHOLD (Direction Angle))
             THEN (Set DIRECTION (Storm) to average
                  DIRECTION (Storm))
          END IF
     5.3  IF (X-SPEED (Storm) and Y-SPEED (Storm) are not
             known)
             THEN COMPUTE (X-SPEED (Storm))
                  COMPUTE (Y-SPEED (Storm))
          END IF
     5.4  IF (STORM TOP is not known)
             THEN (Identify probable HAIL IDENTIFIER #1)
          END IF
     5.5  IF (STORM TOP is at least THRESHOLD (Hail #1))
             THEN (Identify positive HAIL IDENTIFIER #1)
          END IF
     5.6  IF (maximum REFLECTIVITY (Storm Component) is
             greater than THRESHOLD (Hail #2))
             THEN (Identify positive HAIL IDENTIFIER #2)
          END IF
```

```
5.7  DO FOR ALL (ELEVATIONs)
     5.7.1  COMPUTE (RADIUS (Storm Component))
     5.7.2  COMPUTE (RANGE (Slant-Storm Component))
     END DO
5.8  DO (ELEVATIONs) FROM (Second lowest) TO (Highest)
     5.8.1  COMPUTE (X-POSITION displacement)
     5.8.2  COMPUTE (Y-POSITION displacement)
     5.8.3  COMPUTE (ANGLE (Between Overhang and Direction))
     5.8.4  COMPUTE (DISTANCE (Between Centroids))
     5.8.5  IF (HEIGHT (Storm Component-Centroid) of the
               lowest elevation STORM COMPONENT is less than
               THRESHOLD (Hail Low) AND HEIGHT (Storm
               Component-Centroid) of current STORM
               COMPONENT is between THRESHOLD (Hail Height))
               THEN
                  IF (Y-POSITION displacement is less than
                     -1)
                     THEN (Identify positive HAIL
                          IDENTIFIER #3)
                  END IF
                  IF (ANGLE (Between Overhang and
                     Direction) is between THRESHOLD
                     (Hail #4))
                     THEN (Identify positive HAIL
                          IDENTIFIER #4)
                  END IF
            END IF
     5.8.6  IF (HEIGHT (Storm Component-Centroid) of the
               current STORM COMPONENT is not between THRES-
               HOLD (Hail Height) and STORM TOP is not
                    known)
               THEN (Identify probable HAIL IDENTIFIER
                    #5)
                    (Identify probable HAIL IDENTIFIER
                    #6)
            END IF
     5.8.7  IF (HEIGHT (Storm Component-Centroid) of the
               current STORM COMPONENT is between THRESHOLD
               (Hail Height))
               THEN IF (REFLECTIVITY (Storm Component)
                       is greater than THRESHOLD (Hail
                       #5))
                       THEN (Identify positive HAIL
                            IDENTIFIER #5)
               END IF
            END IF
     5.8.8  IF (HEIGHT (Storm Component-Centroid) of the
               lowest elevation STORM COMPONENT is less than
               THRESHOLD (Hail Low) AND HEIGHT (Storm Com-
               ponent-Centroid) of the current STORM COM-
               PONENT is between THRESHOLD (Hail Height))
               THEN COMPUTE (STORM OVERHANG)
                    IF (STORM OVERHANG is greater than
                       THRESHOLD (Hail #6))
                       THEN (Identify positive HAIL
                            IDENTIFIER #6)
                    END IF
            END IF
     END DO
5.9  IF (HEIGHT (Storm Component-Centroid) of a STORM
        COMPONENT is above the HEIGHT (Storm Component-
        Centroid of the lowest STORM COMPONENT that has
        STORM OVERHANG)
        THEN
           DO FOR ALL (STORM COMPONENTs with HEIGHT (Storm
                      Component-Centroid between THRESHOLD
                      (Hail Height))
              COMPUTE (DISTANCE (Storm Top and Mid
                      Level))
              IF (DISTANCE (Storm Top and Mid Level) is
                 less than or equal to the RADIUS
                 (Storm Component) of the highest STORM
                 COMPONENT that has STORM OVERHANG)
                 THEN (Identify positive HAIL
                      IDENTIFIER #7)
              END IF
           END DO
     END IF
5.10 IF (STORM TOP is unknown)
        THEN (Identify probable HAIL IDENTIFIER #7)
     END IF
5.11 IF (STORM TOP is unknown AND HEIGHT (Storm Component-
        Centroid) of the STORM COMPONENT at the highest
        elevation is less than THRESHOLD (Hail High Low))
        THEN (Identify probable HAIL IDENTIFIER #2, #3
             and #4)
     END IF
5.12 COMPUTE (WEIGHT (Positive))
     WRITE (WEIGHT (Positive))
5.13 COMPUTE (WEIGHT (Probable))
     WRITE (WEIGHT (Probable))
5.14 COMPUTE (CONFIDENCE FACTOR)
     WRITE (CONFIDENCE FACTOR)
5.15 IF (CONFIDENCE FACTOR is greater than THRESHOLD
        (Low Confidence))
        THEN COMPUTE (SCORE)
             WRITE (SCORE)
        ELSE (LABEL the current STORM as having
             insufficient data)
     END IF
     5.16 IF (SCORE is less than THRESHOLD (Score)
             THEN (LABEL the current STORM as a non-hail
                  producer)
             ELSE
                IF (CONFIDENCE FACTOR is greater than
                   THRESHOLD (High Confidence) AND SCORE is
                   greater than or equal to THRESHOLD (High
                   Score))
                   THEN (LABEL the current STORM as a
                        hail producer)
                   ELSE (LABEL the current STORM as a
                        probable producer of hail)
                END IF
          END IF
     5.17 IF (maximum REFLECTIVITY (Equivalent) is greater
             than THRESHOLD (High Reflectivity) AND LABEL is
             not hail producer)
             THEN
                (LABEL the current STORM as a probable hail
                producer)
                WRITE (maximum REFLECTIVITY (Equivalent))
          END IF
     5.18 WRITE (LABEL)
     END DO

END ALGORITHM (HAIL)
```

3.2 COMPUTATION

3.2.1 NOTATION

SSavg = average SPEED (Storm), the average speed of n STORMs, in km/hr.

SS = SPEED (Storm), speed of a STORM, in km/hr. If the speed is not determined by the STORM POSITION FORECAST [008] algorithm, then its value is set as unknown.

DSavg = average DIRECTION (Storm), the average direction from which STORMs are moving, in radians.

DSnth = nth DIRECTION (Storm), direction from which the nth STORM is moving, in radians. If the direction is not determined by the STORM POSITION FORECAST [008] algorithm, then its value is set as being unknown.

XS = X-SPEED (Storm), the speed of a STORM in the X-direction, in km/hr.

YS = Y-SPEED (Storm), the speed of a STORM in the Y-direction, in km/hr.

RSC = RADIUS (Storm Component), the radius of a circle whose area is equivalent to the area of the STORM COMPONENT of a particular STORM at a particular ELEVATION, in kilometers.

i = INDEX (Elevation), the index for ELEVATION.

A = AREA (Storm Component), area of a STORM COMPONENT at a particular ELEVATION, in km^2.

RSSC = RANGE (Slant-Storm Component), slant range of a centroid at a particular ELEVATION, in kilometers.

X = X-POSITION, X-position of the CENTROID, in kilometers.

Y = Y-POSITION, Y-position of the CENTROID, in kilometers.

SCR = SCORE, a ratio of the total weight of the positive HAIL IDENTIFIERS to the total possible weight of all successful tests, in percent.

HSCC = HEIGHT (Storm Component-Centroid), height of the centroid of a STORM COMPONENT at a particular ELEVATION above the ground, in kilometers.

PHI# = ELEVATION, elevation angle, in radians.

Xdis = X-POSITION displacement, the displacement between the X-position of the centroid of a STORM COMPONENT at a particular ELEVATION and the location of the centroid of another STORM COMPONENT of the same STORM at the lowest ELEVATION, in kilometers.

Tdif = TIME (Difference), the time difference between the beginning of the volume scan and the current scan time, in hours.

Ydis = Y-POSITION displacement, the displacement between the Y-position of the centroid of a STORM COMPONENT at a particular ELEVATION and the location of the centroid of another STORM COMPONENT of the same STORM at the lowest ELEVATION, in kilometers.

ANG = ANGLE (Between Overhang and Direction), the horizontal angle formed by a line from the centroid of the STORM COMPONENT of a STORM at a particular ELEVATION and the centroid of the STORM COMPONENT of the same STORM at the lowest ELEVATION to a line that is parallel to the direction of the storm's movement, in radians.

Xmid = Midlevel X-POSITION, the X-position of a centroid of a STORM COMPONENT at a midlevel altitude (5-12 kilometers), in kilometers.

Ymid = Midlevel Y-POSITION, the Y-position of a centroid of a storm component at a midlevel altitude (5-12 km), in kilometers.

Xhgh = Highest X-POSITION, the X-position of a centroid of the highest STORM COMPONENT, in kilometers.

Yhgh = Highest Y-POSITION, the Y-position of a centroid of the highest STORM COMPONENT, in kilometers.

Xlow = Lowest X-POSITION, the X-position of a centroid of the lowest STORM COMPONENT, in kilometers.

Ylow = Lowest Y-POSITION, the Y-position of a centroid of the lowest STORM COMPONENT, in kilometers.

DC = DISTANCE (Between Centroids), the horizontal distance between the centroid of the STORM COMPONENT of a STORM at the lowest ELEVATION and the centroid of the STORM COMPONENT of the same STORM at some higher ELEVATION, in kilometers.

OVH = STORM OVERHANG, the distance between the edge of the STORM COMPONENT of a STORM at a particular ELEVATION and the centroid of the STORM COMPONENT of the same storm at the lowest ELEVATION, in kilometers.

DTM = DISTANCE (Storm Top and Mid Level), the horizontal distance between the centroid of a STORM COMPONENT of a STORM at a midlevel altitude (5 to 12 kilometers) and the centroid of the STORM COMPONENT of the same STORM at the highest ELEVATION, in kilometers.

WPO = WEIGHT (Positive), total weight of all the positive HAIL IDENTIFIERs identified. Weight is an integer.

WPR = WEIGHT (Probable), total weight of all the probable HAIL IDENTIFIERs identified. Weight is an integer.

CFA = CONFIDENCE FACTOR, the level of confidence in the prediction of hail for a particular storm, in percent.

LAB = LABEL, a descriptive identifier written for each storm, which identifies the probability of hail production as being positive, potential, probable, a non-hail producer, or that there is insufficient data to analyze the storm.

Note 1: This algorithm has been implemented on a 32 bit minicomputer.

Note 2: Precision is equivalent to the units x 10^{-4} unless otherwise stated.

3.2.2 SYMBOLIC FORMULAS

COMPUTE (X-SPEED (Storm))

$XS_n = (SS_n)[-\sin(DS_n)]$

where n is the number of storms

COMPUTE (Y-SPEED (Storm))

$YS_n = (SS_n)[-\cos(DS_n)]$

where n is the number of storms

COMPUTE (average SPEED (Storm))

$$SSavg = [\sum_{n} SS_n]/n$$

where n is the number of storms whose speeds are known.

COMPUTE (average DIRECTION (Storm))

$$DSavg = \tan^{-1}\{[(\sum_{n} XS_n)/n]/[(\sum_{n} YS_n)/n]\}$$

where n is the number of storms whose speeds are known.

COMPUTE (RADIUS (Storm Component))

$$RSC_{ni} = (A_{ni}/\pi)^{1/2}$$

where n is the number of storms.

COMPUTE (RANGE (Slant-Storm Component))

$$RSSC_{ni} = (X_{ni}^{2} + Y_{ni}^{2})^{1/2}/\cos \phi$$

where n is the number of storms.

COMPUTE (HEIGHT (Storm Component-Centroid)

$$HCSS_{ni} = \{RSSC_{ni}^{2}/[(2)(1.21)(6371)]\} + \{RSSC_{ni}(\sin(\phi_i))\}$$

where n is the number of storms, 1.21 is the index of refraction and 6371 is the radius of Earth in kilometers.

COMPUTE (X-POSITION displacement)

$$Xdis_{ni} = X_{ni} - [Xlow_n - (XS_n)(Tdif_i)]$$

where n is the number of storms.

COMPUTE (Y-POSITION displacement)

$$Ydis_{ni} = Y_{ni} - [Ylow_n - (YS_n)(Tdif_i)]$$

where n is the number of storms.

COMPUTE (ANGLE (Between Overhang and Direction))

$$ANG_{ni} = \pi + [\tan^{-1}(Xdis_{ni}/Ydis_{ni})] - (DSavg \text{ or } DS_n)$$

where n is the number of storms.

COMPUTE (DISTANCE (Between Centroids))

$DC_{ni} = [(Xdis_{ni})^2 + (Ydis_{ni})^2]^{1/2}$

where n is the number of storms.

COMPUTE (STORM OVERHANG)

$OVH_{ni} = DC_{ni} + RSC_{ni} - RSClow_n$

where n is the number of storms.

COMPUTE (DISTANCE (Storm Top and Mid Level))

$$DTM_n = [(Xmid_n - Xhgh_n)^2 + (Ymid_n - Yhgh_n)^2]$$

where n is the number of storms.

COMPUTE (WEIGHT (Positive))

WPO = Sum of the WEIGHT of positive HAIL IDENTIFIER #n, where n is the index for positive identifiers.

COMPUTE (WEIGHT (Probable))

WPR = Sum of the WEIGHT of probable HAIL IDENTIFIER #n, where n is the index for probable identifiers.

COMPUTE (CONFIDENCE FACTOR)

CFA = 100 - WPR

COMPUTE (SCORE)

SCR = (WPO/CFA) x 100

4.0 OUTPUTS

4.1 IDENTIFICATION

LABEL is a descriptive identifier written for each STORM, which indicates whether the STORM is a positive hail producer, a potential or probable hail producer, a non-hail producer, or that there is insufficient data to analyze the storm. A set of supplemental output values for each label are as follows, WEIGHT(Positive), CONFIDENCE FACTOR, SCORE and maximum REFLECTIVITY(Storm).

4.2 DISTRIBUTION

No distribution of outputs other than for storm identification or display are anticipated at this time.

5.0 INFERENCES

5.1 LIMITATIONS

This algorithm assumes that all storm components are circular and the centroid is at the geometrical center of the circle. Large deviations from this assumption may result in errors in the determination of hail indicators that are based on "storm overhang."

5.2 FUTURE DEVELOPEMENTS

The algorithm is currently undergoing testing to optimize the WEIGHTs associated with each of the hail identifiers.

ECHO TOPS

ALGORITHM DESCRIPTION

NX-DR-03-013/17

MAJOR REVISIONS SINCE MAY 1984

Echo Tops (013)

1. All algorithms appearing in the May 1984 report have undergone the following changes:

   a. Editorial and typographical changes.

   b. Explicit declaration of data element precision.

   c. Renaming of data element names and symbols to achieve unique naming.

   d. Data Dictionary changes resulting from other changes.

2. The definition of the fifteen categories was clarified by specifying that the Operational Threshold column of Table 1 was to be used.

3. All references to dBZ were changed to dBZe.

4. In section 1.3, 18.3 dBZ was changed to 18.5 dBZe.

1.0 PROLOGUE

1.1 FUNCTIONAL DESCRIPTION

The Echo Tops algorithm estimates echo (non-zero reflectivity category) top heights for 4 kilometer (east-west) by 4 kilometer (north-south) grid boxes. A grid box represents the area on the earth where a single value of reflectivity will be assigned. The height of the echo top is measured from ground level to the mid-point of the radar radial beam for the highest non-zero reflectivity category per grid box.

1.2 SOURCE

The Echo Tops algorithm described herein was supplied by Mr. Robert Saffle of the NWS's Techniques Developement Laboratory. It represents the implementation used on the D/RADEX radars.

1.3 PROCESSING ENVIRONMENT

The Echo Tops algorithm only requires reflectivity data. This algorithm does not use the "raw" reflectivity factor data obtained from the radar. Several preprocessing steps are carried out before the data are input to the algorithm. The NWS preprocessing performed on the data is described by the following operations.

First, the standard $1/r^2$ range correction is performed on the data. A correction is then made for oxygen absorption of microwave energy. The linear attenuation correction of 6.5×10^{-3} dB/km for a 10 cm radar is then performed. The resulting reflectivity factor data values for each sample volume are assigned a number representing fifteen categories as shown in the Operational Threshold column of Table 1. If the return power is less than 18.5 dBZe it is assigned a value of zero. The data is also filtered to remove any spurious data. A data point must have at least two adjacent points with a category value of at least one, otherwise isolated point is removed. That is, at least two of the four possible sample volumes at a particular elevation with adjoining sides to the sample volume in question must be in category one or above. This final data set is the one used as input to the Echo Tops algorithm.

Table 1. Values of reflectivity, rainfall rate, and liquid water content for RADAP II reflectivity intensity categories.

RADAP II VALUE	VIP VALUE	THRESHOLD ZE (mm^6/m^3)	THRESHOLD LOG ZE	OPERATIONAL THRESHOLD dBZe	THRESHOLD DVIP VALUE 1/2 dBZe	THRESHOLD R(200)* (in/hr)	MID-POINT ZE (mm^6/m^3)	MID-POINT LOG ZE	MID-POINT R(200)* (in/hr)	MID-POINT R(55)** (in/hr)	MID-POINT M**** (g/m^3)
1	1	68	1.83	18.5	37	.02	182	2.26	.04	.08	0.0
2		295	2.47	24.5	49	.05	593	2.77	.08	.16	0.1
3	2	891	2.95	29.5	59	.10	2140	3.33	.17	.39	0.3
4		3388	3.53	35.5	71	.23	5153	3.71	.30	.67	0.5
5		6918	3.84	38.5	77	.36	9309	3.97	.44	.97	0.6
6	3	11700	4.07	40.5	81	.50	15150	4.18	.59	1.32	0.8
7		18600	4.27	42.5	85	.67	19950	4.30	.70	1.57	1.0
8		21300	4.33	43.5	87	.83	28400	4.45	.87	1.94	1.2
9	4	35500	4.55	45.5	91	1.00	45850	4.66	1.18	2.63	1.6
10		56200	4.75	47.5	95	1.33	67800	4.83	1.50	3.36	2.0
11		79400	4.90	49.0	98	1.66	93200	4.97	1.84	4.11	2.4
12	5	107000	5.03	50.5	101	2.00	155500	5.19	2.52	5.64	3.2
13		204000	5.31	53.0	106	3.00	264000	5.42	3.51	7.86	4.3
14		324000	5.51	55.0	110	4.00	396000	5.60	4.55	7.86***	5.4
15	6	468000	5.67	56.5	113	5.00				7.86***	5.4***

* $Z = 200R^{1.6}$ ** $Z = 55R^{1.6}$ *** Lower category values used to minimize effects of hail **** $M = 3.44 \times 10^{-3} Z^{4/7}$

2.0 INPUTS

2.1 IDENTIFICATION

AZIMUTH = Azimuthal position, in radians. Precise to 10^{-3} radians.

CATEGORIES = Categorized effective reflectivity factor data for each SAMPLE VOLUME.

ELEVATION = Elevation angle, in radians.

RANGE (Slant) = The slant range to the center of a SAMPLE VOLUME, in kilometers.

BOX (4 km x 4 km Grid) = Square grid boxes which are 4 km on a side and cover ranges from 0 to 230 km.

2.2 ACQUISITION

AZIMUTH, ELEVATION, and RANGE (Slant) are quantities measured directly during the radar data acquisition process.

CATEGORIES are obtained from the NWS preprocessing algorithm as described in Section 1.3.

BOX(4 km x 4km Grid) is a system supplied parameter.

3.0 PROCEDURE

3.1 ALGORITHM

```
BEGIN ALGORITHM (ECHO TOPS)

1.0  DO FOR ALL (ELEVATIONs)
     1.1  DO FOR ALL (AZIMUTHs)
          1.1.1  DO FOR ALL (RANGEs (Slant))
                 1.1.1.1  IF (CATEGORIES value is not equal
                             to zero)
                             THEN COMPUTE (HEIGHT (Echo Tops))
                                  Map polar position of
                                  HEIGHT onto the BOX (4 km
                                  x 4 km Grid).
                          END IF
                 END DO
          END DO
     1.2  DO FOR ALL (BOXes (4 km x 4 km Grid))
          1.2.1  COMPUTE (TOP (Echo))
          1.2.2  WRITE (TOP (Echo))
          1.2.3  IF (TOP (Echo) is found at the highest
                    ELEVATION)
                    THEN
                       Mark the TOP (Echo) as being at the
                       highest ELEVATION.
                 END IF
          END DO
     END DO

2.0  WRITE (TOPs (Echo))

END ALGORITHM (ECHO TOPS)
```

3.2 COMPUTATION

3.2.1 NOTATION

HTOP = HEIGHT (Echo Tops), the height of non-zero values in CATEGORIES for each SAMPLE VOLUME, in kilometers. Precise to 10^{-4} kilometers.

RS = RANGE (Slant), the slant range to the center of a SAMPLE VOLUME, in kilometers. Precise to 10^{-4} kilometers.

PHI# = ELEVATION, elevation angle, in radians. Precise to 10^{-3} radians.

TOP = TOP (Echo), the greatest height of an echo computed for a BOX (4 km x 4 km Grid), in kilometers. Precise to 10^{-4} kilometers.

RE = RADIUS (Earth), radius of the Earth (6371), in kilometers. Precise to 10^{-4} kilometers.

NOTE: Precision is to the units specified unless otherwise stated.

3.2.2 SYMBOLIC FORMULAS

COMPUTE (HEIGHT (Echo Tops))

$$HTOP = (RS)(\sin \phi) + [((RS)(\cos \phi))^2/(4/3\ RE)]$$

COMPUTE (TOP (Echo))

$$TOP = HTOP_n \text{ if } HTOP_n > TOP$$

where n is the number of height values within a BOX(4 km x 4 km Grid)

4.0 OUTPUTS

4.1 IDENTIFICATION

TOPs (Echo) are estimates of echo top heights for each 4 x 4 kilometer grid box. The product may be converted to thousands of feet for display purposes.

4.2 DISTRIBUTION

These echo top values could be used directly for display or used as input to other algorithms.

5.0 INFERENCES

5.1 LIMITATIONS

The precision for measuring the height decreases with range because of beam broadening. At a range of 230 kilometers the one-half beam width is 4040 meters.

The algorithm does not correct for data contamination from side lobes. The height of echo tops could be overestimated from this effect.

The echo tops may be undetectable by the radar at close range with a limited range of elevations.

5.2 FUTURE DEVELOPMENTS

No future developments have been identified for this algorithm.

SEVERE WEATHER PROBABILITY
ALGORITHM DESCRIPTION
NX-DR-03-015/18

MAJOR REVISIONS SINCE MAY 1984

Severe Weather Probability (015)

1. All algorithms appearing in the May 1984 report have undergone the following changes:

    a. Editorial and typographical changes.

    b. Explicit declaration of data element precision.

    c. Renaming of data element names and symbols to achieve unique naming.

    d. Data Dictionary changes resulting from other changes.

1.0 PROLOGUE

1.1 FUNCTIONAL DESCRIPTION

The purpose of the SEVERE WEATHER PROBABILITY (SWP) algoithm is to determine the probability that an identified radar echo is part of a severe storm. A severe storm is defined as one with a tornado or funnel cloud, surface hail $\geq$ 3/4 inch, and/or wind gusts $\geq$ 50 knots or reported wind damage.

A multiple screening regression technique was used to determine the degree of association of vertically integrated liquid (VIL) water content predictors with subsequent observations or reports of severe weather. The approach depended on the collection of a statistically significant sample of candidate predictors and a corresponding sample of reported occurrences of severe weather. The probability of occurrence of severe weather was expressed in terms of a weighted, linear combination of the predictors selected by the screening process. The screening process for predictors was repeated until the reduction of variance by additional predictors reached a predetermined lower limit.

The data sample was from the 1972 WSR-57 digital radar archives of the National Severe Storms Laboratory. There were 109 cells defined from VIL data obtained in this experiment, of which 23 were associated with severe weather events. Only those cells containing VIL values greater than ten were considered. The sixteen predictors derived from vertically integrated liquid water content are as follows:

*1. VIL SIZE, Number of grid boxes (n) covered by echo

2. maximum VIL, VILSmax

*3. VIL WEIGHT, (n)(VILSmax)

4. VIL MASS, $\sum_{m} n\ [(m+1\ ,\ldots,\ m+5)]\ [(m+5)/5]$

where m = 5,10,15 ..., 100.

5.	SVG10,	Size (n) of echo having VIL > 10
*6.	SVG15,	Size (n) of echo having VIL > 15
*7.	SVG20,	Size (n) of echo having VIL > 20
*8.	SVG25,	Size (n) of echo having VIL > 25
9.	BIN15,	1 if VIL > 15, 0 otherwise
10.	BIN20,	1 if VIL > 20, 0 otherwise

11. BIN25, 1 if VIL > 25, 0 otherwise

12. BIN30, 1 if VIL > 30, 0 otherwise

13. BIN35, 1 if VIL > 35, 0 otherwise

14. BIN40, 1 if VIL > 40, 0 otherwise

15. BIN45, 1 if VIL > 45, 0 otherwise

16. LIFETIME, Lifetime of VIL cell

Only five of the original 16 predictors are used in the final regression equation (marked with asterisks). The weights derived for each predictor are given in Section 3.2. This equation was derived for a specific set of NSSL data. Analysis of future data sets archived for NEXRAD may yield different regression equations for different parts of the country.

1.2 SOURCE

The SWP algorithm described herein has been implemented for the D/RADEX experiment conducted by the National Weather Service (NWS). Mr. Robert Saffle of the NWS Techniques Development Laboratory supplied the D/RADEX information.

REFERENCES

Alaka, M.A., R.C. Elvander, and R.E. Saffle, 1979: Nowcasts and Short-Range (0-2 Hour) Forecasts of Thunderstorms and Severe Convective Weather for Use in Air Traffic Control. Dept. of Trans. Report No. FAA-RD-79-98, 31 pp.

Elvander, R.C., 1977: Relationships between Radar Parameters Observed with Objectively Defined Echoes and Reported Severe Weather Occurrences. Preprints, 10th Conference on Severe Local Storms, Omaha, Nebraska, Amer. Meteor. Soc., 73-76.

1.3 PREPROCESSING ENVIRONMENT

This algorithm requires the output identified in the VERTICALLY-INTEGRATED LIQUID WATER [006] algorithm.

2.0 INPUTS

2.1 IDENTIFICATION

LIQUID WATER (Integrated) = the integrated liquid water values (per grid box), for a column within a STORM, in kg/km^2.

SEVERE WEATHER COEFFICIENTS = The set of coefficients (SW1...SW6) of a regression equation that determines the severe weather probability. The default values are SW1 = 6.90, SW2 = 7.39, SW3 = 0.22, SW4 = 3.67, SW5 = 0.01 and SW6 = 2.55.

BOX (SWP) = An area surrounding a VIL grid box, in km^2.

SWP BOX SIZE = The size of the SWP analysis area, in odd numbered multiples of 4 X 4 kilometer boxes (e.g. 28 X 28, 36 X 36, 44 X 44... etc.) The default size is 44 X 44 kilometers.

2.2 ACQUISITION

LIQUID WATER (Integrated) values are acquired from the VERTICALLY-INTEGRATED LIQUID WATER [006] algorithm.

SEVERE WEATHER COEFFICIENTS are site dependent adaptation parameters.

SWP BOX SIZE is a site dependent adaptation parameter.

BOX (SWP) is a system supplied parameter.

3.0 PROCEDURES

3.1 ALGORITHM

```
BEGIN ALGORITHM (SWP)

1.0  Locate the maximum LIQUID WATER (Integrated-SWP) value.

2.0  Identify the SWP BOX SIZE area comprised of the grid
     box with the maximum LIQUID WATER (Integrated-SWP) value,
     and the surrounding grid boxes, as a BOX (SWP).

3.0  DO (LIQUID WATER (Integrated)) FROM largest TO smallest
     3.1  IF (LIQUID WATER (Integrated) is not located
             within an identified BOX (SWP))
             THEN (Identify the SWP BOX SIZE area surround-
                  ing the grid box as a BOX (SWP))
          END IF
     END DO

4.0  DO FOR ALL (BOXes (SWP))
     4.1  COMPUTE (VIL SIZE)
     4.2  COMPUTE (VIL WEIGHT)
     4.3  COMPUTE (NO. OF GRID BOXES WITH VIL > 15)
     4.4  COMPUTE (NO. OF GRID BOXES WITH VIL > 20)
     4.5  COMPUTE (NO. OF GRID BOXES WITH VIL > 25)
     4.6  COMPUTE (PROBABLIITY (Severe Weather))
     4.7  WRITE (PROBABILITY (Severe Weather))
     END DO

END ALGORITHM (SWP)
```

3.2 COMPUTATION

3.2.1 NOTATION

VS = VIL SIZE, the number of grid boxes (n) covered by echo, i.e., with integrated liquid water values.

VWT = VIL WEIGHT, the size of the VIL cell (VS) multiplied by the maximum value of VIL (VILSmax) in the cell, in kg/km^2.

VIL = LIQUID WATER (Integrated), the integrated liquid water values (per grid box), for a column within a STORM, in kg/km^2

VILS = LIQUID WATER (Integrated-SWP), the integrated liquid water values in a BOX (SWP), in kg/km^2.

VILSmax = maximum LIQUID WATER (Integrated-SWP), the maximum integrated liquid water value in a BOX (SWP), in kg/km^2.

FTN = NO. OF GRID BOXES WITH VIL > 15, number of grid boxes with VIL greater than 15.

TWY = NO. OF GRID BOXES WITH VIL > 20, number of grid boxes with VIL greater than 20.

TWF = NO. OF GRID BOXES WITH VIL > 25, number of grid boxes with VIL greater than 25.

PWX = PROBABILITY (Severe Weather), the probability of severe weather, in percent.

BSP = BOX(SWP), an area surrounding a VIL grid box in km^2.

SW1-SW6 = SEVERE WEATHER COEFFICIENTS, the set of coefficients of a regression equation that determines the severe weather probability. The default values are SW1 = 6.90, SW2 = 7.39 SW3 = 0.22, SW4 = 3.67, SW5 = 0.01, SW6 = 2.55.

NOTE : Precision is to the units specified unless otherwise stated.

3.2.2 SYMBOLIC FORMULAS

COMPUTE (VIL SIZE)

VS = Count of grid boxes within a BOX (SWP) with VIL values.

COMPUTE (VIL WEIGHT)

VWT = (VS) (VILSmax)

COMPUTE (NO. OF GRID BOXES WITH VIL > 15)

FTN = Count of grid boxes within a BOX (SWP) with a VIL value greater than fifteen.

COMPUTE (NO. OF GRID BOXES WITH VIL > 20)

TWY = Count of grid boxes within a BOX (SWP) with VIL value of greater than twenty.

COMPUTE (NO. OF GRID BOXES WITH VIL > 25)

TWF = Count of grid boxes within a BOX (SWP) with VIL value of greater than twenty-five.

COMPUTE (PROBABILITY (Severe Weather))

PWX = SW1 + SW2(TWY) + SW3(VS) - SW4(FTN) + SW5(VWT) - SW6(TWF)

4.0 OUTPUTS

4.1 IDENTIFICATION

A set of PROBABILITY (Severe Weather) values is output, with each value corresponding to a BOX (SWP).

4.2 DISTRIBUTION

These values can be sent directly to an output device for display. They can also be used by other algorithms to determine which echoes should be given priority when seeking to identify areas of severe weather.

5.0 INFERENCES

5.1 LIMITATIONS

As with any empirical, statistical technique, there is the possibility that the statistical sample does not reflect the true population. How much of the variance in the true population is explained by this equation is not known; in the dependent sample, twenty-four (24) percent of the variance was explained.

The lack of earth curvative correction described in the LIMITATIONS Section of the VIL (006) algorithm apply.

5.2 FUTURE DEVELOPMENTS

No plans for change are known at this time.

MODIFIED VELOCITY VOLUME PROCESSING

ALGORITHM DESCRIPTION

NX-DR-03-016/25

MAJOR REVISIONS SINCE MAY 1984

Modified Velocity Volume Processing (016)

1. All algorithms appearing in the May 1984 report have undergone the following changes:

    a. Editorial and typographical changes.

    b. Explicit declaration of data element precision.

    c. Renaming of data element names and symbols to achieve unique naming.

    d. Data Dictionary changes resulting from other changes.

2. In the symbolic formula for KINEMATIC PARAMETERS the formulas for VME and VMN were corrected.

3. The 1X7 matrix for MXP was removed.

1.0 PROLOGUE

1.1 FUNCTIONAL DESCRIPTION

The Modified Velocity Volume Processing (VVP) algorithm is a statistical regression method for calculating the vector wind field over the radar's surveillance area. The algorithm, as presently configured, assumes the wind to be linear within the data volume used in the algorithm. The algorithm best fits the observed radial velocities into the kinematic parameters of the linear wind model. The kinematic parameters are solved for volumes (SECTORS) pi/6 radians by 30 kilometers by two elevation angles of observation. The algorithm computes the kinematic parameters for each SECTOR using least-squares statistical regression. There are seven kinematic parameters computed from which kinematic properties of the mesoscale wind field (e.g., divergence) could be made. The first two kinematic parameters derived are the east-west and north-south irrotational components of the wind. The third parameter is a direct measure of the horizontal deformation of the wind. The fourth parameter is the derivative of the east-west component of the wind about the X-axis. The fifth kinematic parameter is the derivative of the north-south component of wind about the Y-axis. The sum of the fourth and fifth kinematic parameters yields the horizontal divergence. The final two kinematic parameters are vertical gradients of the east-west and north-south components of the wind, i.e., the vertical shear of the horizontal wind. These last two parameters were included to improve the estimates of the other five parameters.

1.2 SOURCE

This algorithm has been implemented at the National Severe Storms Laboratory (NSSL), Norman, Oklahoma. Originally proposed by Waldteufel and Corbin (1979) using a full 360° radar scan, Koscielny *et al*. (1982) modified the algorithm to use sectors on the order of 30°.

REFERENCES

Koscielny, A.J., R.J. Doviak, and R. Rabin, 1982: Statistical considerations in the estimation of divergence from single Doppler radar and application to prestorm boundry-layer observation. *J. Appl. Meteor.*, *21*, 197-210.

Waldteufel, P. and H. Corbin, 1979: On the analysis of single - Doppler radar data. *J. Appl. Meteor.*, *18*, 532-542.

1.3 PROCESSING ENVIRONMENT

This algorithm requires Doppler radial velocities that have been unfolded in range and magnitude. Also, the data must be devoid of bad data, e.g., radar echoes due to ground clutter, anomalous propagation, and point targets such as aircraft.

2.0 INPUTS

2.1 IDENTIFICATION

AZIMUTH = Azimuthal position, in radians.

ELEVATION = Elevation angle, in radians.

RANGE (Slant) = The slant range to the center of a SAMPLE VOLUME, in kilometers.

VELOCITY (Doppler) = Doppler velocities in a data SAMPLE VOLUME, in km/hr.

SECTOR = Reflectivity values from a subset of a radar scan in PI/6 radians by 30 kilometer by 2 elevation angle volume, in radians and kilometers. Radians are precise to 10^{-3} radians. Kilometers are precise to 10^{-4} kilometers.

2.2 ACQUISITION

AZIMUTH, ELEVATION, and RANGE (Slant) are quantities measured directly during the radar data acquisition process.

VELOCITY (Doppler) is obtained from a preprocessing algorithm that performs the functions discussed in the processing environment section. The velocities can be averaged over range intervals of up to 7 km to reduce the number of computations and, thus, speed up execution of the algorithm.

3.0 PROCEDURE

3.1 ALGORITHM

```
BEGIN ALGORITHM (MODIFIED VVP)

1.0 Partition the radar scans at the two lowest elevation
    angles into pi/6 radian x 30 kilometer SECTORs.

2.0 DO FOR ALL (SECTORs)
    2.1  COMPUTE (KINEMATIC PARAMETERS)
    2.2  WRITE (KINEMATIC PARAMETERS)
    END DO

END ALGORITHM (MODIFIED VVP)
```

3.2 COMPUTATION

3.2.1 NOTATION

KP = KINEMATIC PARAMETERS, parameters that are used to estimate atmospheric motions.

MXP = MATRIX (Predictor), an m by n matrix of predictor variables where m is the dimension for KINEMATIC PARAMETERS and n is the dimension for the Doppler velocities in a SECTOR.

TRN = TRANSPOSE, the transpose of a vector or matrix.

VD = VELOCITY (Doppler), Doppler velocities in a data SAMPLE VOLUME, in km/hr. Precise to .36 km/hr.

VME = VELOCITY (Modified East-West), the modified component of the east-west wind, in km/hr. Precise to .36 km/hr.

VNS = VELOCITY (North-south), the v (north-south) component of the wind speed, in km/hr. Precise to .36 km/hr.

VMN = VELOCITY (Modiied North-South), the modified component of the north-south wind, in km/hr. Precise to .36 km/hr.

VEW = VELOCITY (East-West), the u (east-west) component of the wind speed, in km/hr. Precise to .36 km/hr.

DVX = DERIVATIVE OF v (In X-Direction), derivative of the v-component of wind about the x-axis, in 1/hr.

DUY = DERIVATIVE OF u (In Y-Direction), derivative of the u-component of wind about the Y-axis, in 1/hr.

DEF = DEFORMATION (Horizontal), horizontal deformation of the wind field, in 1/hr.

DUX = DERIVATIVE OF u (In X-Direction), derivative of the u-component of wind about the X-axis, in 1/hr.

DUZ = DERIVATIVE OF u (In Z-Direction), derivative of the u-component of wind about the Z-axis, in 1/hr.

DVY = DERIVATIVE OF v (In Y-Direction), derivative of the v-component of wind about the Y-axis, in 1/hr.

DVZ = DERIVATIVE OF v (In Z-direction), derivative of the v-component of wind about the Z-axis, in 1/hr.

PHI#eff = effective ELEVATION, effective elevation angle, in radians. Precise to 10^{-3} radians.

PHI# = ELEVATION, the elevation angle, in radians. Precise to 10^{-3} radians.

RS = RANGE (Slant), the slant range to the center of a SAMPLE VOLUME, in kilometers. Precise to 10^{-4} kilometers.

REeff = effective RADIUS (Earth), the effective radius of the Earth if the radius appears larger than its true value doe to downward bending of the radar beam, in kilometers. Precise to 10^{-4} kilometers.

AZ = AZIMUTH, azimuthal position, in radians. Precise to 10^{-3} radians.

XSEC = X-POSITION(Sector), X-position of the center of a SECTOR limited by range, azimuth and elevation, in kilometers. Precise to 10^{-4} kilometers.

YSEC = Y-POSITION(Sector), Y-position of the center of a SECTOR limited by range, azimuth and elevation, in kilometers. Precise to 10^{-4} kilometers.

ZSEC = Z-POSITION(Sector), Z-position of the center of a SECTOR limited by range, azimuth and elevation, in kilometers. Precise to 10^{-4} kilometers.

Note: Precision is equivalent to the units unless otherwise stated.

3.2.2 SYMBOLIC FORMULA

COMPUTE (KINEMATIC PARAMETERS)

$$KP = [(MXP_{nm}^{TRN})(MXP_{nm})]^{-1}[(MXP_{nm}^{TRN})(VD_n)] \qquad \text{where;}$$

n is the dimension for VELOCITY (Doppler) in a SECTOR and m is the dimension for KINEMATIC PARAMETERS.

KP^{TRN} = (SHV, SHU, DEF, DUX, DUY, DUZ, DVZ), and

$VME = VEW + [Y(DUX - DUY)/2]$

$VMN = VNS - [X(DVX - DUY)/2]$

$DEF = DUY + DVX$, and

$$MXP_{nm} = \begin{vmatrix} MXP_{1,m} \\ MXP_{2,m} \\ o \\ o \\ o \\ o \\ MXP_{n,m} \end{vmatrix} \qquad \text{where;}$$

$$
MXP^{TRN}_{m,i} = \left[\begin{array}{l}
\cos(\phi eff)\ \sin(AZ) \\
\cos(\phi eff)\ \cos(AZ) \\
\cos(\phi eff)[RS_i\ \cos(\phi eff)\ \cos(AZ) \\
\quad \sin(AZ) - (X\cos(AZ) + Y\sin(AZ))/2] \\
\cos(\phi eff)[(RS_i)\cos(\phi eff)\ \sin(AZ) - \\
\quad XSEC]\ \sin(AZ) \\
\cos(\phi eff)[(RS_i)\cos(\phi eff)\ \cos(AZ) - \\
\quad YSEC]\ \cos(AZ) \\
\cos(\phi eff)[(RS_i)\sin(\phi eff) - \\
\quad (RS^2\cos^2\phi/2REeff) - ZSEC]\ \sin(AZ) \\
\cos(\phi eff)[(RS_i)\sin(\phi eff) - \\
\quad (RS^2\cos^2\phi/2REeff) - ZSEC]\ \cos(AZ) \\
\qquad\qquad\qquad , \text{ and}
\end{array} \right]
$$

$\phi eff = \phi + \tan^{-1}\{(RS)\cos(\phi)/[(REeff) + (RS)\sin(\phi)]\}$

$REeff = 4/3\ RE$

4.0 OUTPUTS

4.1 IDENTIFICATION

KINEMATIC PARAMETERS is a set of kinematic parameters of the wind field for each SECTOR. There are seven kinematic parameters for each SECTOR, output in the following order:

- The modified east-west component of the wind.
- The modified north-south component of the wind.
- The horizontal deformation of the wind.
- The derivative of the east-west component of the wind about the X-axis, centered at the origin.
- The derivative of the north-south component of the wind about the Y-axis, centered at the origin.
- The derivatives of the east-west and north-south components of wind, respectively, about the Z-axis, centered at the origin.

4.2 DISTRIBUTION

The value of the kinematic parameters of the wind field could be used in other algorithms or be formed into products.

5.0 INFERENCES

5.1 LIMITATIONS

This algorithm assumes the wind field is linear over the measured volume. The linearity assumption can be checked by some simple plotting techniques. For example, for a given analysis volume, the measured radial velocity is plotted versus the linearly modeled radial velocities. Deviations of the wind field from linearity will show as a nonrandom scattering of the measured radial velocities about a 45° line. This type of test of the linearity assumption could be automated through test statistics, such as those described by Draper and Smith (1966) applied to the deviations of the measured radial velocities from the modeled velocities. Nonlinearities in the wind field bias the kinematic parameters. The derivative terms are more sensitive to biasing than the wind components and the bias could be larger than the actual derivative. Because this algorithm is designed to be applied to low elevation angles, the vertical wind and its spatial derivatives are not estimated and their neglect in the algorithm should have little effect.

5.2 FUTURE DEVELOPMENTS

Research is continuing at the National Severe Storms Laboratory to find ways to improve the current version of the Modified VVP algorithm and further test its accuracy.

PRECIPITATION PREPROCESSING

ALGORITHM DESCRIPTION

NX-DR-03-017/39

MAJOR REVISIONS SINCE MAY 1984

Precipitation Preprocessing (017)

1. All algorithms appearing in the May 1984 report have undergone the following changes:

    a. Editorial and typographical changes.

    b. Explicit declaration of data element precision.

    c. Renaming of data element names and symbols to achieve unique naming.

    d. Data Dictionary changes resulting from other changes.

2. The hybrid scans have been sectorized. Formerly, only the range increment could be specified.

1.0 PROLOGUE

1.1 FUNCTIONAL DESCRIPTION

The execution timing of the PRECIPITATION PREPROCESSING algorithm is controlled by the completion of a volume scan. The schedule for completion of volume scans containing data needed by this algorithm may depend on atmospheric conditions (see the Precipitation Detection support function and section 5.1 of this algorithm). When the Precipitation Detection support function indicates that no precipitation has occurred during the past hour, a volume scan containing at least the lowest two elevation angles specified by the ELEVATION/RANGE BOUNDARIES must be completed at least once every 10 minutes. At the completion of each of these volume scans during non-precipitation periods, this algorithm must be executed but it will not require any input data other than a precipitation detected flag (indicating no precipitation in the previous hour) obtained from the Precipitation Detection support function.

When the Precipitation Detection support function indicates that precipitation has been detected during the previous hour, this algorithm must be executed at the completion of each volume scan. During these precipitation periods, the PRECIPITATION PREPROCESSING algorithm prepares reflectivity factor data for input to the PRECIPITATION RATE algorithm [018]. The PRECIPITATION RATE algorithm requires data from elevation scans composited to form a single HYBRID SCAN. The four scans are normally obtained during a sampling period not to exceed 2 minutes at a frequency of at least one every 5 minutes. The elevation angles of the elevation scans used will depend on the local topography and clutter conditions at each site, but most often the four scans will be obtained from the lowest four elevation angles between approximately 0.5 and 3.5 degrees. These elevation angles must be separated by 0.9 to 1.1 degrees. Under certain conditions, when precipitation amounts and areal extent are small (see Precipitation Detection support function and section 5.1 of this algorithm), the sampling period for the four scans may be increased from 2 to 4 minutes and the frequency may be reduced from once every 5 minutes to once every 10 minutes. Data from multiple tilt elevation angles are being included to:

- o Assist in the further reduction of residual ground clutter, anomalous propagation, RF interference, and spurious noise which may still exist following the preprocessing done earlier in the NEXRAD processing stream.
- o Provide capability to construct a composite low-altitude array from the lower elevation scans in order to obtain rainfall estimates from data obtained at a more nearly uniform altitude as a function of range.

- Enable the incorporation of techniques to minimize the problems associated with abnormal beam refractions and losses.

The azimuth and range limits for the sectors used to construct the hybrid from each of the four elevation scans are given by the ELEVATION/RANGE/AZIMUTH BOUNDARIES. The sectors from the two lowest elevation angles used overlap in order to test the suitability of the lowest scan and for the bi-scan maximization outlined below. For processing purposes (interpolating isolated and completely blocked values) data from up to 1 km in range and up to 2 degrees in azimuth beyond the boundaries of the sector as described by the ELEVATION/RANGE/AZIMUTH BOUNDARIES may be used by this algorithm.

After the data are assembled, isolated reflectivity values are eliminated and suspect reflectivity values are modified. Occultation corrections for both partial obscurations and complete obscurations (up to 2 degrees in azimuth) are also performed.

Each sample volume which potentially may be used in the HYBRID SCAN is first adjusted for any significant partial (up to 60%) occultations of the beam resulting from man-made or natural obstacles. The intent is to correct for the percentage of the two way beam intensity which is obscured from each volume. This is done by simply adding a predetermined value, based on individual site surveys, to the equivalent reflectivity factor at each sample volume which requires adjustment for these losses. The adjustment is applied in 1 dBZe steps and ranges from 1 to 4 dBZe, where the magnitude of the adjustment is proportional to the percent of the beam obscured.

Then, each sample volume is inspected to determine whether or not it is isolated. An isolated sample volume is defined as follows: 1) the equivalent reflectivity factor value is greater than a low minimum threshold, 2) less than two of the eight neighbors within the same elevation scan have equivalent reflectivity factor values greater than the minimum threshold. The equivalent reflectivity factor values of isolated sample volumes are then set to zero.

Sample volumes with a value greater than a maximum (outlier) threshold are assumed not to be valid. Each outlier will be replaced with an interpolated value (a simple average of the values of all eight neighbors in the same elevation scan) only if all eight neighbors have values below the outlier threshold. Otherwise, it is set to a low non-zero value (in order that the sample volume is still included in the area calculations of the area reduction test which follows). These changes are made in such a way that subsequent alterations of outliers are not affected by the changes to those previously identified.

After adjusting for any outliers, an occultation correction is applied to sample volumes which are completely (>60%) blocked. In this case, an interpolation must be performed using the values of the two closest sample volumes, on both sides, and at the same range and elevation, which are not also completely blocked. This is done only if 2 degrees or less in azimuth are completely blocked. When more than 2 degrees of azimuth are identified as being completely blocked, at a particular elevation, no attempt is made to interpolate, because of the large errors which would result. These changes are made in such a way that subsequent alterations of blocked sample volumes are not affected by the changes to those made previously.

The next function performed by the algorithm is to determine whether data from the lowest elevation scan will be used at all in building the HYBRID SCAN. The lowest scan data are used in building the HYBRID SCAN if any one of the following tests is passed:

- The total echo area is less than a threshold for significant areal coverage. The total echo area consists of sample volumes from all sectors at the lowest elevation with values greater than a low minimum intensity threshold.
- The area averaged reflectivity of significant echo areas from all sectors at the lowest elevation is less than a specified value.
- The third test is based on the ratio of two values: The first value is the area covered by sample volumes with significant echoes from the lowest scan sectors which are not significant at the second lowest scan. ("Significant" echoes exceed a certain threshold). The second value is the total area of significant echoes from the lowest scan sectors. If the ratio of the first value to the second is below a certain threshold, then the lowest scan is considered acceptable.

The intent of these tests is to identify cases where the lowest elevation is significantly contaminated by residual ground clutter, anomalous propagation, RF interference or spurious noise, and to avoid using it in these cases.

The sectors are then used to construct the HYBRID SCAN. Where sectors from the two lowest elevation scans overlap, the maximum of values from the two lowest elevation scan sectors at each range and azimuth are used in the HYBRID SCAN. This procedure, known as bi-scan maximization, is applied out to a certain range, beyond which the lowest tilt values are used. If the lowest elevation is deemed unusable, the second lowest is used for all these ranges and azimuths.

These values, combined with sectors from the two higher tilts, form the HYBRID SCAN.

The HYBRID SCAN consists of 82,800 values on a 1 degree by 1 km polar grid from 1 to 230 km.

1.2 SOURCE

The PRECIPITATION PREPROCESSING algorithm was developed by the Radar Hydrology Group of the National Weather Service's Hydrologic Research Laboratory. This algorithm has been based on experiences gained through the use of real-time rainfall estimation from the D/RADEX system, the GATE project, and other experimental projects as will as an in-depth analysis of ways with which weather radar data could be better used for hydrometeorological purposes.

REFERENCES

Ahnert, P.R., M.D. Hudlow, and E.R. Johnson, 1984: Validation of the "on-site" Precipitation Processing System for NEXRAD. Preprints, 22nd Radar Meteor. Conf., AMS, Boston, Mass.

Ahnert, P.R., M.D. Hudlow, E.R. Johnson, D.R. Greene, and M.R. Dias, 1983: Proposed "on-site" precipitation processing system for NEXRAD. Preprints, 21st Radar Meteor. Conf., AMS, Boston, Mass.

Hudlow, M.R., D.R. Greene, P.R. Ahnert, W.F. Krajewski, T.R. Sivaramakrishnan, M.R. Dias, and E.R. Johnson, 1983: Proposed off-site precipitation processing system for NEXRAD. Preprints, 21st Radar Meteor. Conf., AMS, Boston, Mass.

1.3 PROCESSING ENVIRONMENT

It is assumed that several preprocessing steps will be applied to the equivalent reflectivity factor data before the data are input to the PRECIPITATION PREPROCESSING algorithm (for example, clutter suppression). Care must be taken to ensure that these steps are accomplished without loss of data quality or quantitative accuracy.

Some of the important preprocessing steps expected before data are input to this algorithm include:

- Oxygen absorption correction [function of antenna elevation angle, range, height of antenna, and the assumed atmospheric state (probably the U.S. Standard Atmosphere)],
- Assignment of zero values to all reflectivities below a specified/determined noise threshold,

- o Signal processing in ground clutter areas as specified by clutter map to suppress ground clutter, as well as anomalous propagation where possible, and other sources of interference (where possible, equivalent reflectivity factor values from these sources should be reduced to a level below 10 dBZe without degradation of the accuracy in the reflectivity estimates exceeding one, or at most, two dBZe), and

- o Automatic calibration and quality control functions as desirable and feasible.

Furthermore, this algorithm assumes that the data being input have been converted to equivalent reflectivity factor data, hereafter referred to simply as reflectivity factor data, using the standard assumptions in the classical radar equation. In addition, it is assumed that corrections have been applied to adjust for any known biases and losses resulting from the signal processing, alterations in equipment calibration, dry radome attenuation (eventually, wet radome effects should be addressed in the preprocessing or within the PRECIPITATION PREPROCESSING or other PRECIPITATION algorithms themselves), and any other known losses.

If some of these effects are not taken into account, the information required to make adjustments should be made available for input to the PRECIPITATION PREPROCESSING or other PRECIPITATION algorithms, and the algorithms should be modified to make the required adjustments to the reflectivity data before using them.

The algorithm includes four quality control procedures (partial occultation correction, isolated sample volume check, outlier check, complete occultation correction) which must be done for each sample volume which potentially may be used in the HYBRID SCAN. These steps must be accomplished in such a way that the resultant effects on the data are identical to the result of doing each step, one at a time, for all sample volumes.

If the range or azimuth resolution of the base data exceeds the 1 km by 1 degree specified for the input to this algorithm, then two alternative strategies are available. The first strategy is simply to average the higher resolution data upstream in the processing from this algorithm. The averaging technique is important, as it will affect the bias in the averaged value. The ideal averaging scheme, for precipitation estimation purposes, is to convert the reflectivity factor data to rainfall rate (see the PRECIPITATION RATE [018] algorithm); then average all of the higher resolution sample volumes that fall within each of the specified 1 degree by 1 km cells, then perform the reverse conversion.

An accceptable alternative is to average in Z units, i.e., convert the logarithmic units (dBZe) to linear units (Ze), then average in linear units, then convert the linear units on the 1 km by 1 degree grid back to logarithmic units. Averaging directly in logarithmic units (dBZe) is not acceptable, nor is it acceptable to perform some operation other than averaging (e.g., taking the higher resolution sample volume closest to the center of the 1 km by 1 degree cell, or using an interpolation scheme to produce the best estimate at the center of the 1 degree by 1 km cell).

The second strategy is to defer the averaging process until after certain of the initial quality control steps are done. This averaging could be done at any point in the processing stream before the computation of the AREA (Lowest Elevation Echo) (Step 4.12 in the algorithm). The second strategy would certainly increase the computational burden for this algorithm. However, it might be useful if the quality control steps indicated in this algorithm (isolated sample volumes, outliers, and occultation corrections) duplicate those of other NEXRAD algorithms which require retention of the higher resolution data. If the second strategy is adopted, the averaging process must still comply with the criteria described above.

Especially for use in the higher level (regional/national) processing, it will be critical that certain file management information be appended to the basic rainfall data. This information will be required to identify certain characteristics about the data up to that point in the processing stream, and it will be used as part of the information for accomplishing more discriminating quality control funtions at the higher level of processing.

2.0 INPUTS

2.1 IDENTIFICATION

TIME (volume Scan) = Time at which a volume scan was completed. A precision of at least 1/1200 hour.

TIME (Stamp) = Time at which the Precipitation Detection support function was last executed. A precision of at least 1/1200 hour.

TIME (Last Precipitation Detected) = The time at which the Precipitation Detection support function last detected precipitation. A precision of at least 1/1200 hour.

SAMPLE VOLUME = A data sample volume whose dimensions are 1 degree in azimuth, 1 km in range, and 1 degree in depth (perpendicular to the radar beam).

NOTE: Within this algorithm the data SAMPLE VOLUME is treated as a horizontal projection (1 degree in azimuth by 1 km in range).

ELEVATION = Elevation angle, in radians. A precision of at least .001 radians.

ELEVATION/RANGE/AZIMUTH BOUNDARIES = The minimum and maximum range and azimuth sector boundaries and ELEVATIONs (4) for which reflectivity factor data are used to build the hybrid scan. The values used will vary from site to site, depending on local terrain, clutter condition and elevation angles used.

For a site located on relatively flat terrain they will be defined approximately follows:

Elevation Angle (radians)	Ranges Required (km)	Azimuth (deg)
highest (0.056-0.061)	1 to 20	0 - 359
second highest (0.040-0.045)	21 to 35	0 - 359
second lowest (0.024-0.030)	36 to 230	0 - 359
lowest (0.009-0.014)	51 to 230	0 - 359

For a site located east of a mountain range they might, for example, be defined as follows:

Elevation Angles (radians)	Ranges (km)	Azimuth (deg)
highest (0.056-0.061)	1 to 20	0 - 359
highest (0.056-0.061)	21 to 60	188 - 359
highest (0.056-0.061)	61 to 70	331 - 359
highest (0.056-0.061)	121 to 136	175 - 187
second highest (0.040-0.045)	21 to 35	0 - 187
second highest (0.040-0.045)	61 to 70	188 - 330
second highest (0.040-0.045)	71 to 230	188 - 007
second highest (0.040-0.045)	61 to 70	0 - 007
second lowest (0.024-0.030)	36 to 60	0 - 187
second lowest (0.024-0.030)	61 to 120	8 - 187
second lowest (0.024-0.030)	121 to 136	8 - 174
second lowest (0.024-0.030)	137 to 230	8 - 187
lowest (0.009-0.014)	51 to 60	0 - 187
lowest (0.009-0.014)	61 to 120	8 - 187
lowest (0.009-0.014)	121 to 136	8 - 174
lowest (0.009-0.014)	137 to 230	8 - 187

REFLECTIVITY FACTOR (DBZE) = The effective radar reflectivity factor of a SAMPLE VOLUME, in dBZe.

OCCULTATION CODEs = Coded values for each SAMPLE VOLUME which are based on the percentage of the total (two way) beam intensity which is obscured by natural or man-made obstacles under normal propagation conditions.

Code	Occultation (%)
0	0-10,>60[1]
1	11-29
2	30-43
3	44-55
4	56-60
5	>60[2]

[1] SAMPLE VOLUME is part of a completely obscured region extending over more than 2 degrees in azimuth.

[2] SAMPLE VOLUME is part of a completely obscured region extending over no more than 2 degrees in azimuth.

minimum THRESHOLD (Reflectivity-1)	= The minimum reflectivity factor considered to be non-zero in the test for isolated SAMPLE VOLUMEs, in in dBZe.
maximum THRESHOLD (Reflectivity-1)	= The maximum reflectivity which which could be expected when precipitation is occurring, in in dBZe.
REFLECTIVITY (Tilt Test)	= Low reflectivity, approximately 0-10 dBZe.
RANGE (Tilt Test)	= The inner and outer range boundaries between which the lowest and second lowest elevation reflectivity data are compared, in kilometers. Will be approximately 40 and 150 km.
minimum AREA (Echo)	= The minimum area of precipitation echoes in the low tilt sectors and between the inner and outer RANGEs (Tilt Test) which must be exceeded in order to do the tilt test (600), in km^2.
minimum REFLECTIVITY (Area-Averaged)	= The area-averaged reflectivity factor for all SAMPLE VOLUMEs in the lowest elevation sectors between the inner and outer RANGEs (Tilt Test), which must be exceed in order to do the tilt test (10.0), in dBZe. A precision of at least 0.1 dBZe.

maximum AREA (Percent Reduction) = The percentage of echo area in the lowest elevation sector and between the inner and outer RANGEs (Tilt Test) which is eliminated by going to the second lowest elevation, which when exceeded, flags the lowest elevation scan as being bad (50), in percent.

maximum RANGE (Bi-Scan) = Maximum range at which the bi-scan maximization procedure is applied, in kilometers.

TIME (Elevation Scan) = The time at the beginning and end of each elevation scan.

PRECIPITATION STATUS MESSAGE = An alphanumeric message which includes the radar ID, TIME(Stamp), current radar status, current operational mode, current scan strategy, TIME(Last Precipitation Detected), CATEGORY (Precipitation), number of gages in data base, and time since last update to the gage data base.

CATEGORY(Precipitation) = The precipitation category currently in effect.

CATEGORY	MEANING
0	No precipitation detected during the past hour
1	Significant precipitation detected during the past hour
2	Light precipitation detected during the past hour

2.2 ACQUISITION

PRECIPITATION STATUS MESSAGE, CATEGORY(Precipitation), Time (Stamp), and TIME (Last Precipitation Detected) are obtained from a Precipitation Detection support function.

SAMPLE VOLUMEs, ELEVATIONs, TIMEs (Volume Scan) and TIMEs (Elevation Scan) are intrinsic system parameters and are acquired directly from the radar.

ELEVATION/RANGE/AZIMUTH BOUNDARIES are unit adapation parameters.

REFLECTIVITY FACTOR (DBZE) data are acquired from the NEXRAD base data.

OCCULTATION CODEs are unit adaptation parameters based on site survey data providing the topographic cross sections (perpendicular to the radar beam axis) and assuming standard propagation conditions.

Minimum THRESHOLD (Reflectivity-1) and REFLECTIVITY (Tilt Test) are system adaptation parameters based on empirical/ theoretical studies.

Maximum THRESHOLD (Reflectivity-1), maximum AREA (Percent Reduction), and maximum RANGE (Bi-Scan) are seasonally dependent unit adaptation parameter values based on empirical/theoretical studies.

RANGEs (Tilt Test), minimum AREA (Echo), and minimum REFLECTIVITY (Area-Averaged) are unit adaptation parameters based on empirical/theoretical studies.

3.0 PROCEDURE

3.1 ALGORITHM

```
BEGIN ALGORITHM (PRECIPITATION PREPROCESSING)

1.0  Clear FLAG (Zero Hybrid).

2.0  IF  (CATEGORY (Precipitation) indicates no
        precipitation during the past hour)
        THEN
           Set FLAG (Zero Hybrid).
        ELSE
           IF (Reflectivity data specified by ELEVATION/RANGE/
              AZIMUTH BOUNDARIES not included in this volume
              scan)
           THEN
              STOP and restart after next volume scan is complete
                   with the PRECIPITATION PREPROCESSING algor-
                   ithm.
           END IF
     END IF

3.0  WRITE (FLAG (Zero Hybrid))

4.0  IF (FLAG (Zero Hybrid) set)
        THEN
        4.1  Set average TIME (Scan) to TIME (Volume Scan).
        4.2  WRITE (average TIME (Scan))
        ELSE
        4.3  Assemble a set of sectors comprised of
             SAMPLE VOLUMEs based on a set of ELEVATION/
             RANGE/AZIMUTH BOUNDARIES and input ELEVATIONs.
        4.4  DO FOR ALL (Partially occulted SAMPLE VOLUMEs)
                COMPUTE (OCCULTATION (Partial Adjustment))
             END DO
        4.5  DO FOR ALL (SAMPLE VOLUMEs)
                IF (REFLECTIVITY FACTOR (DBZE) is great-
                   er than minimum THRESHOLD (Reflectivity-1)
                   and the number of neighboring SAMPLE VOLUMEs
                   greater than minimum THRESHOLD (Reflectiv-
                   ity-1) is less than two)
                   THEN (Mark the SAMPLE VOLUME as
                        isolated)
                        Keep count of the NUMBER (Isolated
                        Sample Volumes).
                END IF
             END DO
```

```
4.6  WRITE (NUMBER (Isolated Sample Volumes))
4.7  Replace the REFLECTIVITY FACTOR (DBZE) of
     isolated SAMPLE VOLUMEs with a value of 0
     (lower limit of REFLECTIVITY FACTOR (DBZE)).
4.8  DO FOR ALL (SAMPLE VOLUMEs)
        IF (REFLECTIVITY FACTOR (DBZE) is greater
           than maximum THRESHOLD (Reflectivity-1))
           THEN (Mark the SAMPLE VOLUME as an
                outlier)
              IF (All eight adjoining SAMPLE VOLUMEs
                 are less than maximum THRESHOLD
                 (Reflectivity-1) AND all eight not
                 previously identified as an
                 outlier)
                 THEN COMPUTE (REFLECTIVITY
                              (Interpolated))
                              Replace REFLECTIVITY FACTOR
                              (DBZE) with REFLECTIVITY
                              Interpolated).  Keep
                              count of the NUMBER
                              (Interpolated Outliers).
                 ELSE Replace REFLECTIVITY FACTOR
                      (DBZE) with REFLECTIVITY
                      (Tilt Test).  Keep count of
                      the NUMBER (Replaced Outliers).
              END IF
        END IF
     END DO
4.9  WRITE (NUMBER (Interpolated Outliers))
4.10 WRITE (NUMBER (Replaced Outliers))
4.11 DO FOR ALL (Completely occulted SAMPLE VOLUMEs)
        IF (Complete blockage extends over two
           degrees, or less, in azimuth)
           THEN COMPUTE (REFLECTIVITY (Complete
                        Occultation))
        END IF
     END DO
4.12 COMPUTE (AREA (Lowest Elevation Echo))
4.13 IF (AREA (Lowest Elevation Echo) is greater
        than minimum AREA (Echo))
        THEN
           COMPUTE (Reflectivity (Area-Averaged))
           IF (REFLECTIVITY (Area-Averaged) is
              greater than minimum REFLECTIVITY
              (Area-Averaged))
```

```
                      THEN
                         COMPUTE (AREA (Percent Reduction))
                         WRITE (AREA (Percent Reduction))
                         IF (AREA (Percent Reduction) is
                            greater than maximum AREA
                            (Percent Reduction))
                            THEN
                               Do not use the lowest scan sec-
                               tors.  Use the second lowest scan
                               sectors.
                            ELSE
                               Use the maximum reflectivity
                               between the two lowest elevation
                               sections (at each range and
                               azimuth where the sectors from the
                               two lowest tilts overlap, out to
                               the maximum RANGE (Bi-Scan)).
                               Keep count of the number of
                               second tilt SAMPLE VOLUMEs
                               selected.
                         END IF
                      ELSE
                         Use the maximum reflectivity between
                         the two lowest elevation sections
                         (at each range and azimuth where the
                         sectors from the two lowest tilts
                         overlap, out to the maximum RANGE (Bi-
                         Scan)).  Keep count of the number of se-
                         cond tilt SAMPLE VOLUMEs selected.
                   END IF
                ELSE
                   Use the maximum reflectivity between the
                   two lowest elevation sections (at each
                   range and azimuth where the sectors from the
                   two lowest tilts overlap, out to the maximum
                   RANGE (Bi-Scan)).
                   Keep count of the number of second tilt
                   SAMPLE VOLUMEs selected.
             END IF
        4.14 COMPUTE (RATIO (Bi-Scan))
        4.15 WRITE (RATIO (Bi-Scan))
        4.16 Assemble the HYBRID SCAN.
        4.17 WRITE (HYBRID SCAN)
        4.18 COMPUTE (average TIME (Scan))
        4.19 WRITE (average TIME (Scan))
      END IF

END ALGORITHM  (PRECIPITATION PREPROCESSING)
```

3.2 COMPUTATION

3.2.1 NOTATION

OC = OCCULTATION CODEs, coded values for each SAMPLE VOLUME which are based on the percentage of the total (two-way) beam intensity which is obscured by natural or man-made obstacles under normal propagation conditions.

OCP = OCCULTATION (Partial Adjustment), an additive adjustment for beam occultation, in dBZe.

NIO = NUMBER (Interpolated Outliers), number of SAMPLE VOLUMEs for which the REFLECTIVITY (Interpolated) was computed.

NIS = NUMBER (Isolated SAMPLE VOLUMEs), number of SAMPLE VOLUMEs whose REFLECTIVITY FACTOR(DBZE) is greater than the minimum THRESHOLD (Reflectivity-1) but are surrounded by less than two SAMPLE VOLUMEs whose REFLECTIVITY FACTOR(DBZE) is greater than the minimum THRESHOLD (Reflectivity-1).

NRO = NUMBER (Replaced Outliers), number of outliers which have at least one neighbor which is also an outlier and whose REFLECTIVITY FACTOR(DBZE) is replaced with the REFLECTIVITY (Tilt Test).

DBZE = REFLECTIVITY FACTOR (DBZE), the effective radar reflectivity factor a SAMPLE VOLUME, in dBZe. A precision of at least 1 dBZe and a dynamic range of at least 0 to 71 dBZe are required.

ZEI = REFLECTIVITY (Interpolated), the average of all eight neighboring SAMPLE VOLUME reflectivities, in dBZe.

ZCO = REFLECTIVITY (Complete Occultation), the average of the reflectivity factor values at the same range on either side of a completely occulted SAMPLE VOLUME, in dBZe.

RS = RANGE (Slant), the slant range to the center of a SAMPLE VOLUME, in kilometers. Precise to 0.1 km.

ALE = AREA (Lowest Elevation Echo), echo area including those SAMPLE VOLUMEs with a reflectivity factor greater than the REFLECTIVITY (Tilt Test) from the lowest elevation sectors and between the inner and outer RANGEs (Tilt Test), in km^2.

FZH = FLAG (Zero Hybrid), a set or cleared flag indicating, if set, that no precipitation exists in the current scan.

ASV = AREA (Sample Volume), the area of a particular SAMPLE VOLUME in the RATE SCAN to the nearest 0.01 km^2, in km^2.

AEmin = Minimum AREA (Echo), the minimum area of precipitation echoes in the low tilt sectors between the inner and outer RANGEs (Tilt Test) which must be exceeded in order to do the tilt test, in km^2.

ZAVlow = REFLECTIVITY (Area-Averaged), the area-averaged reflectivity factor for all SAMPLE VOLUMEs from the lowest elevation sector between the inner and outer RANGEs (Tilt Test) with reflectivity factor greater than or equal to the REFLECTIVITY (Tilt Test), in dBZe. Precise to 0.1 dBZe.

APR = AREA (Percent Reduction), the percentage echo area from the lowest elevation sectors and between the inner and outer RANGEs (Tilt Test) which is eliminated by going to the second lowest elevation.

ASL = AREA (Second Elevation Echo), the echo area which satisfies the requirements of AREA (Lowest Elevation Echo) at the lowest elevation but not at the second lowest elevation, in km^2.

BIR = RATIO (Bi-Scan), the ratio of the number of SAMPLE VOLUMEs used from the second lowest elevation scan to the total number of SAMPLE VOLUMEs used in the Bi-Scan maximization procedure.

HS = HYBRID SCAN, reflectivity factor data on a 1 degree by 1 km polar grid from 1 to 230 km, in dBZe. These data were composited from four elevation scans by the PRECIPITATION PREPROCESSING algorithm. A precision of at least 1 dBZe and dynamic range of at least 0 to 71 dBZe are required.

TESbeg = beginning TIME (Elevation Scan), time at which the beginning of an elevation scan was started. A precision of at least 1/1200 hour and an accuracy of 1/120 hour are required.

TESend = ending TIME (Elevation Scan), the time at which the end of a elevation scan occurred. A precision of at least 1/1200 and an accuracy of 1/120 hour are required.

TSavg = average TIME (Scan), the average scan time of the four elevation scans used to construct the HYBRID SCAN. A precision of at least 1/1200 hours and accuracy to within 1/120 hours are required. This is a time of occurrence, not duration.

j = INDEX (Azimuth), the index for AZIMUTH.

PI# = PI, a mathematical constant (3.1416), unitless.

Note: Precision will be units specified unless otherwise stated

3.2.2 SYMBOLIC FORMULAS

COMPUTE (OCCULTATION (Partial Adjustment))

$$DBZE = DBZE_{meas} + OCP\ (OC)$$

where;

OCP (dBZe)	OC (code)
0	0
1	1
2	2
3	3
4	4
0	5

COMPUTE (REFLECTIVITY (Interpolated))

$$ZEI = \frac{\sum_{n=1}^{8} DBZE_n}{8}$$

where;

sum is over all 8 neighboring sample volumes at the same elevation.

COMPUTE (REFLECTIVITY (Complete Occultation))

$$ZCO = 10 \log \frac{10^{DBZE_{j-1}/10} + 10^{DBZE_{j+1}/10}}{2}$$

where;

$DBZE_{j-1}$ and $DBZE_{j+1}$ are the reflectivity values at the same range on either side of the completely (>60%) occulted area.

Note: This subscription assumes that the azimuthal resolution is one degree. If the azimuthal resolution is less than one degree the two nearest (in azimuth) SAMPLE VOLUMEs at the same range, which are not themselves completely occulted, should be used.

COMPUTE (AREA (Lowest Elevation Echo))

$$ALE = \sum_{n} ASV_n$$

where;

sum is over all n sample volumes from the lowest scan sectors and between the inner and outer RANGEs (Tilt Test) whose REFLECTIVITY FACTOR (DBZE) is greater than or equal to REFLECTIVITY (Tilt Test).

and,

$$ASV_n = \frac{2\pi (RS_n)}{360} \times 1 \text{ km}$$

Note: This assumes azimuthal resolution of 1 degree and range resolution of 1 km.

COMPUTE (REFLECTIVITY (Area-Averaged))

$$ZAVlow = \sum_{n} \frac{(ASV_n)(DBZE_n)}{ALE}$$

where;

ASV_n is defined above and is summed under the same conditions as above.

COMPUTE (AREA (Percent Reduction))

$$APR = \frac{ASL}{ALE} (100)$$

where;

ALE is defined above,

and;

$$ASL = \sum_{n} ASV_{n}$$

sum is over all n sample volumes from the lowest scan sectors and between the inner and outer RANGEs (Tilt Test) whose REFLECTIVITY FACTOR (DBZE) at the lowest scan is greater than or equal to the REFLECTIVITY (Tilt Test) and whose REFLECTIVITY FACTOR (DBZE) at the second lowest scan is less than the REFLECTIVITY (Tilt TEST).

COMPUTE (RATIO (Bi-Scan))

$$BIR = \frac{\text{number of sample volumes used from the second lowest scan}}{\text{total number of sample volumes for which the BI-SCAN procedure is normally conducted}}$$

NOTE: BIR = 1 whenever BI-SCAN procedure is not used because of a high AREA (Percent Reduction).

COMPUTE (average TIME (Scan))

$$TSavg = \frac{\sum_{1}^{4}[(TESend_{n} + TESbeg_{n})/2]}{4}$$

where;

sum is over the TIMEs (Elevation Scan) of the four elevation scans used in this algorithm.

4.0 OUTPUTS

4.1 IDENTIFICATION

The HYBRID SCAN, a 1 degree by 1 km resolution scan set of reflectivity factor values (from 1 to 230 km) composited from four elevation scans is output by this algorithm unless no precipitation has occurred during the past hour.

NUMBER (Isolated Sample Volumes), NUMBER (Interpolated Outliers), NUMBER (Replaced Outliers), AREA (Percent Reduction), average TIME (Scan), and RATIO (Bi-Scan) are included in SUPPLEMENTAL DATA.

Average TIME (Scan) and FLAG (Zero Hybrid) are output by this algorithm.

4.2 DISTRIBUTION

The HYBRID SCAN and FLAG (Zero Hybrid) are intended to be input to the PRECIPITATION RATE [018] algorithm.

SUPPLEMENTAL DATA will be input to the PRECIPITATION PRODUCTS [021] algorithm.

Average TIME (Scan) is intended to be input to the PRECIPITATION RATE [018] and PRECIPITATION ACCUMULATION [019] as the time of the HYBRID SCAN and subsequent RATE SCAN, respectively.

.0 INFERENCES

5.1 LIMITATIONS

This algorithm does not account for:

- frozen hydrometer effects, including bright band phenomena
- errors in signal averaging due to strong reflectivity gradients (within the reflectivity sample volumes)
- wet radome attenuation
- intervening rainfall attenuation

If any scan mode in the NEXRAD system fails to meet the requirements of Table 1, the NEXRAD site may completely fail to recognize precipitation occurrence. In addition, if any scan mode does not meet the requirements of Table 1, there can be no assurance that the category of precipitation (0, 1, or 2) as assigned by the Precipitation Detection function (NTR-Appendix D) is representative of current conditions. This is important since the category determines whether or not the more stringent scan mode requirements in table 2 (Category 1) or table 3 (Category 2) must be met by the current scan mode. Failure to meet the requirements of Table 1 at all times, Table 2 when the precipitation category is 1, and Table 3 when the precipitation category is 2, will seriously degrade the performance of the Precipitation Processing Subsystem and result in the generation of unreliable products.

Table 1. Minimal Scan Mode Requirements

Scan Characteristic	Requirements
Range	230 km or more
Range Resolution	2 km or less
Azimuthal Coverage	360°
Azimuthal Resolution	2° or less
Tilts and Repetition	Lowest 2 tilts required by Precipitation Processing Subsystem (see PRECIPITATION PREPROCESSING algorithm) at least every 10 minutes. All 4 tilts required by Precipitation Processing Subsystem at least every 30 minutes.

Table 2. Minimal Scan Mode Requirements -- Maximum Accuracy Precipitation (Category 1)

Scan Characteristic	Requirements
Range	230 km or more
Range Resolution	1 km or even fraction of 1 km (e.g., 1/2, 1/3, 1/4, ...)
Azimuthal coverage	360°
Azimuthal Resolution	1°
Tilts and Repetition	Lowest 4 tilts required by Precipitation Processing Subsystem (see PRECIPITATION PREPROCESSING algorithm), contiguous, sequentially acquired over 2 minutes or less, repeated every 5 minutes or less.

Table 3. Minimal Scan Mode Requirements -- Degraded Accuracy Precipitation (Category 2)

Scan Characteristic	Requirements
Range	230 km or more
Range Resolution	1 km or even fraction of 1 km (e.g., 1/2, 1/3, 1/4,...)
Azimuthal Coverage	360°
Azimuthal Resolution	1°
Tilts and Repetition	Lowest 4 tilts required by Precipitation Processing Sybsystem (see PRECIPITATION PREPROCESSING algorithm), contiguous, sequentially acquired over 4 minutes or less, repeated at least every 10 minutes.

5.2 FUTURE DEVELOPMENTS

Adaptation parameter values will be "fine tuned" using actual NEXRAD data.

PRECIPITATION RATE

ALGORITHM DESCRIPTION

NX-DR-03-018/27

MAJOR REVISIONS SINCE MAY 1984

Precipitation Rate (018)

1. All algorithms appearing in the May 1984 report have undergone the following changes:

   a. Editorial and typographical changes.

   b. Explicit declaration of data element precision.

   c. Renaming of data element names and symbols to achieve unique naming.

   d. Data Dictionary changes resulting from other changes.

2. RATE (Area-Averaged Grid Box Precipitation) was changed to RATE (1/4 LFM Grid Box).

3. The definition of dBR was corrected.

1.0 PROLOGUE

1.1 FUNCTIONAL DESCRIPTION

The PRECIPITATION RATE algorithm executes each time the PRECIPITATION PREPROCESSING algorithm is completed. If the FLAG (Zero Hybrid) is on, the algorithm sets the FLAG (Zero Rate) and updates the reference values for the time continuity test. Otherwise, the PRECIPITATION RATE algorithm uses preprocessed reflectivity factor (HYBRID SCAN) data from the PRECIPITATION PREPROCESSING [017] algorithm to estimate precipitation rates for 1 degree by 2 km sample volumes within a radius of 230 km. The RATE SCAN is produced for input to the PRECIPITATION ACCUMULATION [019] algorithm. Also, three quality control related procedures are performed within the PRECIPITATION RATE algorithm.

Precipitation rates are empirically determined from a relationship with reflectivity factor data. The precipitation rates from two adjacent 1 degree by 1 km sample volumes along the same radial are averaged to obtain values for the 1 degree by 2 km RATE SCAN. The RATE SCAN is comprised of 41,400 1 degree by 2 km sample volumes. The rate values are in dBR's (dBR = 10 log [(precipitation rate)/(1/ mm/hr)]).

Based on the time continuity of the total field volumetric precipitation rate on a scan to scan basis, a decision is made whether the current RATE SCAN should be used by the PRECIPITATION ACCUMULATION algorithm or be discarded. This test is intended to identify those cases where the between scan increase/decrease of the total volumetric precipitation rate is greater than the increase/decrease expected from precipitation development/decay. These changes could occur as a result of spurious RF interference, transient system noise, or anomalous propagation. Echo areas from storms entering/leaving the scanning region between scans could also cause this parameter to suddenly increase/decrease.

To minimize the chance of rejecting scans because of echo movements into and out of the field of view, the total volumetric precipitation rate is examined for both the entire field of view and for an area with a radius somewhat less than 230 km (inner radius). The inner radius is computed from a climatological maximum speed for echo movement and the time between scans. This test is only considered valid if the time between the current and last good scan is less than a maximum difference at which time continuity is expected.

A range effect correction is then applied to all RATE SCAN values beyond a specified cut-off range. The correction function contains three coefficients which may vary from site to site and with the season. Inputs to the correction function are the range and precipitation rate. This procedure corrects for the effects of signal degradation due to beam losses and partial beam filling which, on the average, reduce the precipitation rate estimates at further ranges.

The area-averaged precipitation rates over each 1/4 LIMITED FINE MESH (LFM) rectangular grid box (approximately 40 km x 40 km) are computed for those boxes whose centers are located within 230 km of the radar. These are obtained by averaging the rates from all RATE SCAN sample volumes whose centers fall within each 1/4 LFM grid box. These data will be used further downstream at the regional/national processing level for important quality control applications and possibly for the construction of a National Radar Summary Chart.

1.2 SOURCE

The PRECIPITATION RATE algorithm was developed by the Radar Hydrology Group of the National Weather Service's Hydrologic Research Laboratory. This algorithm has been based on experiences gained through the use of real-time rainfall estimation from the D/RADEX system, the GATE project, and other experimental projects as well as an in-depth analysis of ways with which weather radar data could be better used for hydrometeorological purposes.

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Ahnert, P.R., M.D. Hudlow, and E.R. Johnson, 1984: Validation of the "on-site" Precipitation Processing System for NEXRAD. Preprints, 22nd Radar Meteor. Conf., AMS, Boston, Mass.

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1.3 PROCESSING ENVIRONMENT

Reflectivity factor data being used by this algorithm are assumed to have been pre-processed as described in the PRECIPITATION PREPROCESSING [017] algorithm.

The HYBRID SCAN (1 degree by 1 km) data have not been spatially averaged to obtain the 1 degree by 2 km resolution required for precipitation processing. A precipitation rate estimate based on the averaged reflectivity is not identical to the average of the precipitation rates based on the full resolution reflectivity data. Therefore, each pair of 1 degree by 1 km reflectivity values being used to estimate a 1 degree by 2 km precipitation rate are first converted from reflectivity to precipitation rate and then averaged to obtain a RATE SCAN (1 degree by 2 km) value.

The time continuity test checks whether scans are bad. Bad scans are rejected or discarded from further processing by the PRECIPITATION ACCUMULATION and subsequent algorithms. This information is saved so that the number of bad scans can be appended to some of the final precipitation products. The intent of this test is not to identify all cases where bad data may be present. It provides a simple means to remove scans which indicate sudden and unreasonable echo development/ decay.

The Limited Fine Mesh (LFM) grid is a rectangular grid commonly used by the National Weather Service which is based on a polar stereographic projection. An LFM grid box represents an area whose size and shape varies with latitude. Therefore the size and shape of the grid boxes will vary slightly over the area covered by the radar and even more from radar to radar (35 to 45 km over the conterminous U.S. for the 1/4th LFM grid). The 1/4th LFM grid boxes used here are defined to have 1/4th LFM grid points as their centers and a mesh length of 47.625 km at the standard latitude 60° N. The information required to generate the grid are the latitude and longitude of the radar, the mesh length at 60° N latitude, and the standard longitude (105° W).

In order to cover the radar umbrella out to 230 km even at the lower latitudes of the conterminous United States, a 13 x 13 array of 1/4th LFM grid boxes will be required. This array will always be 13 x 13 regardless of the latitude of the site. This grid should be positioned in such a way that the radar site falls within grid box (7,7). This array must be compacted (e.g., elimination of all 0 rows, run-length encoding of rows) to reduce storage and especially communications loadings. Compaction must be done in such a way that the source 13 by 13 array can be reconstructed with the use of nominal computer resources.

Generally rainfall rates or accumulations can be retained in two types of units. The more familiar linear units are mm (for accumulations) or mm/hr (for rates). Logarithmic units can also be used (dBA for accumulations, dBR for rates). There are trade-offs involved in the units chosen. The storage requirements for the logarithmic units are approximately one-half that for linear units (about 8 bits/value as opposed to about 16 bit/value). However, several computations must be done in linear units which necessitates conversions from logarithmic to linear units (and vice versa) if logarithmic units are used. These conversions incur a penalty on CPU time. These algorithms are currently written in logarithmic units.

Wherever a power of 10 or base 10 logarithm is found in these algorithms a conversion from logarithmic units to linear units or vice versa is taking place. This conversion can be done by actually computing the powers and logarithms at each sample volume or through the use of a computation saving technique such as the use of a discrete conversion table or any other technique providing sufficient precision. The use of dBRs and dBAs is intended to reduce storage requirements while maintaining required precision at the small end of the scale. However, as long as the requested precision at the small end of the scale is maintained, some CPU time may be saved by keeping the data in linear (mm/hr or mm) units at the expense of increases in storage requirements. If the data are kept in units of mm/hr or mm the computational steps must be appropriately modified to remove the conversions which are no longer needed. The units used for external communications should be chosen on the basis of communications requirements (e.g. DBA's for the ARRAY PRODUCT (Digital Precipitation)) regardless of the units used for internal computations.

2.0 INPUTS

2.1 IDENTIFICATION

FLAG (Zero Hybrid) = A set or cleared flag indicating, if set, that no precipitation exists in the current scan.

HYBRID SCAN = Reflectivity factor data on a 1 degree by 1 km polar grid from 1 to 230 km, in dBZe. These data were composited from four elevation scans by the PRECIPITATION PREPROCESSING algorithm. A precision of at least 1 dBZe is required.

average TIME (Scan) = The average scan time of the four elevation scans used to construct the HYBRID SCAN. This is a time of occurrence, not duration.

maximum SPEED (Storm) = The climatologically derived maximum expected storm SPEED (90.0), in km/hr.

THRESHOLD (Max Time Difference) = Maximum time between scans (approximately 0.25 hours) allowed by the time continuity test. A precision of at least 0.01 hour is required.

RANGE (Cut-Off) = The range beyond which a range effect correction must be applied (150), in kilometers.

COEFFICIENTS (Range Effect) = Three coefficients used to specify the range effect correction function.

BOX (1/4 LFM Grid) = Rectangular grid box which is 1/4th of the Limited Fine Mesh (LFM) grid used by the National Weather Service. Consists of a file specifying the RATE SCAN data sample volumes whose centers fall within each of the 1/4th LFM grid boxes.

COEFFICIENT (Multiplicative Z-R) = Multiplicative coefficient in the Z-R conversion equation (approximately 300).

COEFFICIENT (Z-R Power) = Power coefficient in the Z-R conversion equation (approximately 1.4).

RATE (Zero Precipitation) = Precipitation rate assumed to be zero precipitation (-17.5), in dBR. A precision of at least 0.5 dBR is required.

PARAMETERS (Time Continuity #1) = The allowable rate of change of the ratio of volumetric precipitation rates when the echo area is equal to minimum AREA (Time Continuity) (24.0), in hr^{-1}.

PARAMETER(Time Continuity #2) = The allowable rate of change of the ratio of volumetric precipitation rates when the echo area is equal to the full radar umbrella out to the 230 km range (13.2), in hr^{-1} .

minimum AREA (Time Continuity) = Minimum precipitation area to allow time continuity tests on volumetric precipitation rates, in km^2.

maximum RATE (Echo Area Change) = Maximum rate of change of echo area allowed to pass the time continuity test when the volumetric precipitation rate cannot be tested due to the minimum AREA (Time Continuity), in km^2/hr.

PRECIPITATION STATUS MESSAGE = An alphanumeric message which includes the radar ID, TIME(Stamp), current radar status, current operational mode, current scan strategy, TIME(Last Precipitation Detected), CATEGORY(Precipitation), number of gages in data base, and time since last update to the gage data base.

CATEGORY (Precipitation) = The precipitation category currently in effect.

CATEGORY	MEANING
0	No precipitation detected during the past hour
1	Significant precipitation detected during the past hour
2	Light precipitation detected during the past hour

2.2 ACQUISITION

FLAG (Zero Hybrid), HYBRID SCAN data and average TIME (Scan) are obtained from the PRECIPITATION PREPROCESSING [017] algorithm.

Maximum SPEED (Storm) is a seasonally dependent unit adaptation parameter based on empirical and theoretical studies.

THRESHOLD (Max Time Difference) and RATE (Zero Precipitation) are system adaptation parameters based on empirical or theoretical studies.

RANGE (Cut-Off) and COEFFICIENTS (Range Effect) are seasonally dependent unit adaptation parameters. Initially, they will be specified theoretically based on available experimental data. Eventually, they will be determined empirically from archived data from each site.

BOX (1/4 LFM Grid) is a unit adaptation parameter file which, is generated given the mesh length at 60 degrees N latitude, reference longitude, and exact latitude and longitude of the radar site.

The COEFFICIENTs (Multiplicative Z-R) and COEFFICIENT(Z-R Power) are site adaptation parameters which may be varied seasonally.

PRECIPITATION STATUS MESSAGE and CATEGORY(Precipitation) is obtained by the Precipitation Detection support function.

The minimum AREA (Time Continuity), and maximum RATE (Echo Area Change) are unit adaptation parameters.

The PARAMETERS (Time Continuity) are unit adaptation parameters that may vary seasonally.

3.0 PROCEDURE

3.1 ALGORITHM

```
BEGIN ALGORITHM (PRECIPITATION RATE)

1.0  COMPUTE (average TIME (Scan) difference)

2.0  Clear FLAG (Zero Rate).

3.0  IF (FLAG (Zero Hybrid) is set)
        THEN Set FLAG (Zero Rate).
             Set RATE (Complete Volumetric Precipitation) to
             zero.
             Set RATE (Inner Volumetric Precipitation) to
             zero.
             Set AREA (Complete Precipitation) to zero.
             Set AREA (Inner Precipitation) to zero.
        ELSE
           DO FOR ALL (Pairs of consecutive SAMPLE VOLUMEs
                      along the same radial in the HYBRID
                      SCAN) BY 2
              COMPUTE (RATE SCAN value)
           END DO

           COMPUTE (RADIUS (Inner))
           COMPUTE (RATE (Inner Volumetric Precipitation))
           COMPUTE (AREA (Inner Precipitation))
           COMPUTE (RATE (Complete Volumetric
                   Precipitation))
           COMPUTE (AREA (Complete Precipitation))
     END IF

4.0  Clear FLAG (Bad).

5.0  IF (average TIME (Scan) difference is less than
        THRESHOLD (Max Time Difference) and CATEGORY(Precipita-
        tion) indicates precipitation has occurred during the
        past hour)
        THEN
           IF (RATE (Complete Volumetric Precipitation) less
              than RATE (Inner Reference))
              THEN
                 IF (the AREA (Complete Precipitation) and
                    reference AREA (Inner Precipitation) are
                    both greater than the minimum AREA (Time
                    Continuity))
                    THEN
                       COMPUTE (maximum RATE (Inner Reference))
                       IF (RATE (Inner Reference) greater
                          than maximum RATE (Inner Reference))
                          THEN (Set FLAG (Bad))
                       END IF
                    ELSE
                       COMPUTE (first ABSOLUTE DIFFERENCE)
                       COMPUTE (maximum ABSOLUTE DIFFERENCE)
                       IF (first ABSOLUTE DIFFERENCE greater
                          than maximum ABSOLUTE DIFFERENCE)
                          THEN (Set FLAG (Bad))
                       END IF
                 END IF
           END IF
           IF (RATE (Inner Volumetric Precipitation) is greater
              than RATE (Complete Reference))
              THEN
                 IF (the AREA (Inner Precipitation) and the
                    AREA (Complete Reference) are both
                    greater than the minimum AREA (Time
                    Continuity))
                    THEN
                       COMPUTE (maximum RATE (Inner
                               Volumetric Precipitation))
                       IF (RATE (Inner Volumetric
                          Precipitation) is greater than maximum
                          RATE (Inner Volumetric Precipitation))
                          THEN (Set FLAG (Bad))
                       END IF
                    ELSE
                       COMPUTE (second ABSOLUTE DIFFERENCE)
                       COMPUTE (maximum ABSOLUTE DIFFERENCE)
                       IF (second ABSOLUTE DIFFERENCE is greater
                          than maximum ABSOLUTE DIFFERENCE)
                          THEN (Set FLAG (Bad))
                       END IF
                 END IF
           END IF
     END IF

6.0  WRITE (FLAG (Bad))

7.0  IF (FLAG (Bad) is set)
        THEN
           STOP and restart after next volume scan is
           completed with PRECIPITATION PREPROCESSING [017]
           algorithm.
        ELSE
           The RATE (Complete Reference) value is replaced
           with the RATE (Complete Volumetric Precipitation)
           value.

           The Rate (Inner Reference) value is replaced with
           the RATE (Inner Volumetric Precipitation) value.

           The reference AREA (Complete Precipitation) value
           is replaced with the AREA (Complete Precipitation)
           value.
           The reference AREA (Inner Precipitation) value is
           replaced with the AREA (Inner Precipitation) value.

           The reference average TIME (Scan) value is replaced
           with the average TIME (Scan).
     END IF

8.0  IF (FLAG (Zero Rate) not set)
        THEN
           DO FOR ALL (RATE SCAN sample volumes beyond the
                      RANGE (Cut-Off))
              IF (RATE SCAN value greater than RATE (Zero
                 Precipitation))
                 THEN
                    COMPUTE (RATE (Range Corrected
                            Precipitation))
                    Replace RATE SCAN value with RATE (Range
                    Corrected Precipitation).
              END IF
           END DO
           WRITE (RATE SCAN)
     END IF

9.0  DO FOR ALL (BOX (1/4 LFM Grid))
        IF (FLAG (Zero Rate) set)
           THEN
              IF (RANGE (CENTER 1/4 LFM BOX) less than or equal
                 to 230 km)
                THEN
                    Set RATE (1/4th LFM Grid Box) to Zero
                ELSE
                    Set RATE (1/4th LFM Grid Box) to 7

              END IF
           ELSE
              IF (RANGE (CENTER 1/4 LFM BOX) less than or equal
                 to 230 km)
                THEN
                   COMPUTE (RATE (1/4th LFM Grid Box))
                ELSE
                   Set RATE (1/4th LFM Grid Box) to 7

              END IF
        END IF
        WRITE (RATE (1/4th LFM Grid Box))
     END DO

10.0 WRITE (FLAG (Zero Rate))

END ALGORITHM (PRECIPITATION RATE)
```

3.2 COMPUTATION

3.2.1 NOTATION

RSP = RATE SCAN, precipitation rate data on a 1 degree by 2 km polar grid from 1 to 230 km, in dBR. A precision of at least 0.5 dBR and a dynamic range of at least -18 to 32 dBR are required (not generated for times when FLAG (Zero Rate) or when FLAG (Bad) are set).

AZ = AZIMUTH, azimuthal position, in radians. Precise to 0.0017 radians.

CZM = COEFFICIENT (Multiplicative Z-R), multiplicative coefficient in the Z-R conversion equation.

CZP = COEFFICIENT (Z-R Power), power coefficient in the Z-R conversion equation.

DBZE = REFLECTIVITY FACTOR (DBZE), the effective radar reflectivity factor of a SAMPLE VOLUME, in dBZe. A precision of at least 1 dBZe and a dynamic range of at least 0-71 dBZe are required.

TSavgdif = average TIME (Scan) difference, the difference in time at which scans were taken, in hours to the nearest 1/1200 hour.

TSavg = average TIME (Scan), the average scan time of the four elevation scans used to construct the HYBRID SCAN. A precision of at least 1/1200 hours and accuracy to within 1/120 hours are required. This is a time of occurrence, not duration.

TSavgref = average reference TIME (Scan), the reference scan time (of the last good scan) to the nearest 1/1200 hour.

RI = RADIUS (Inner), the inner radius to the nearest 1.0 kilometer, in kilometers.

SSmax = Maximum SPEED (Storm), the climatologically derived maximum expected storm SPEED to the nearest 1.0 km/hr, in km/hr.

RIV = RATE (Inner Volumetric Precipitation), the total volumetric precipitation rate within the RADIUS (Inner), in mm km^2 hr^{-1}.

FB = FLAG (Bad), when set, designates a precipitation rate scan as including bad data and removes it from further processing.

FZR = FLAG (Zero Rate), a set or cleared flag for each average TIME (Scan) indicating, if set, that all precipitation rate values can be assumed to be equal to RATE (Zero Precipitation).

ASV = AREA (Sample Volume), the area of a particular SAMPLE VOLUME in the RATE SCAN to the nearest 0.01 km^2, in km^2.

RSmid = Midpoint RANGE (Slant), the slant range to the midpoint of a RATE SCAN sample volume in kilometers to the nearest 0.1 km.

RVP = RATE (Complete Volumetric Precipitation), the total volumetric precipitation rate over the entire field of view out to 230 km, in mm km^2 hr^{-1}.

RIR = RATE (Inner Reference), the RATE (Inner Volumetric Precipitation) for the last good scan, in mm km^2 hr^{-1}.

RCR = RATE (Complete Reference), the RATE (Complete Volumetric Precipitation) for the last good scan, in mm km^2 hr^{-1}.

ACP = AREA (Complete Precipitation), the precipitation echo area included within a 230 km radius from the radar, in km^2.

AIP = AREA (Inner Precipitation), the precipitation echo area included within the RADIUS (Inner) from the radar, in km^2.

ACPref = Reference AREA (Complete Precipitation), the value of AREA (Complete Precipitation) from the previous (good) scan, in km^2.

AIPref = Reference AREA (Inner Precipitation), the value of AREA (Inner Precipitation) from the previous (good) scan, in km^2.

ATCmin = Minimum AREA (Time Continuity), minimum precipitation area to allow a time continuity tests on volumetric precipitation rates (200), in km^2.

P1 = PARAMETER (Time Continuity #1), the allowable rate of change of the ratio of volumetric precipitation rates when the echo area is equal to minimum AREA (Time Continuity) in hr^{-1}. Precise to 0.1 hr^{-1}.

P2 = PARAMETER (Time Continuity #2), the allowable rate of change of the ratio of volumetric precipitation rates when the echo area is equal to the full radar umbrella out to the 230 km range in hr^{-1}. Precise to 0.1 hr^{-1}.

RACmax = Maximum RATE (Echo Area Change), maximum rate of change of echo area allowed to pass the time continuity test when the volumetric precipitation rate cannot be tested due to the minimum AREA (Time Continuity), in km^2 hr^{-1}.

RIRmax = Maximum RATE (Inner Reference), the maximum RATE (Inner Reference) for which the current scan can pass the time continuity test, in mm(km^2)hr^{-1}.

RIVmax = Maximum RATE (Inner Volumetric Precipitation), the maximum RATE (Inner Volumetric Precipitation) for which the current scan can pass the time continuity test, in mm (km^2) hr^{-1}.

ADmax = Maximum ABSOLUTE DIFFERENCE, the maximum ABSOLUTE DIFFERENCE in echo area allowed in order to pass the time continuity test, in km^2.

AD1 = First ABSOLUTE DIFFERENCE, the ABSOLUTE DIFFERENCE between the AREA (Complete Precipitation) and the reference AREA (Inner Precipitation), in km^2.

AD2 = Second ABSOLUTE DIFFERENCE, the ABSOLUTE DIFFERENCE between the AREA (Inner Precipitation) and the reference AREA (Complete Precipitation), in km^2.

RRC = RATE (Range Corrected Precipitation), the RATE (Range Corrected Precipitation) with a precision of at least 0.5 dBR and a dynamic range of at least -18 to 32 dBR, in dBR.

C01, C02, C03 = COEFFICIENTS (Range Effect), three coefficients used to specify the range effect correction function.

RGB = RATE(1/4th LFM Grid Box), area-average rate (8 level coded value) in each 1/4 LFM grid square. A 13 by 13 grid of values for each RATE SCAN used in constructing the hourly accumulations.

Note: Precision will be units specified unless otherwise stated.

3.2.2 SYMBOLIC FORMULAS

COMPUTE (average TIME (Scan) difference)

$TSavgdif = TSavg - TSavgref$

COMPUTE (RATE SCAN value)

$RSP(RSmid, AZ) =$

$$10 \log \left[\frac{10^{\frac{(DBZE(RSmid-0.5,AZ)-10 \log CZM)}{CZP}/10}}{2} + \frac{10^{\frac{(DBZE(RSmid+0.5,AZ)-10 \log CZM)}{CZP}/10}}{2} \right]$$

COMPUTE (RADIUS (Inner))

$RI = MAXIMUM\ [150.0; 230.0 - ((TSavgdif)(SSmax))]$

COMPUTE (RATE (Inner Volumetric Precipitation))

$$RIV = \sum_{n} (ASV_n \quad 10^{RSP_n/10})(1mm/hr)$$

where;

$$ASV_n = \frac{2\ \pi\ RSmid_n}{360}\ (2\ km)$$

sum is over all n sample volumes in the RATE SCAN with values greater than the RATE (Zero Precipitation) within the RADIUS (Inner).

COMPUTE (AREA (Inner Precipitation))

$$AIP = \sum_{n} ASV_n$$

where the sum is over the same n sample volumes as above.

COMPUTE (RATE (Complete Volumetric Precipitation))

$$RVP = RIV + \sum_{n} (ASV_n \quad 10^{RSP_n/10}) \text{ (1mm/hr)}$$

where;

sum is over all n sample volumes in the RATE SCAN from the RADIUS (Inner) out to 230 km with values greater than the RATE (Zero Precipitation).

COMPUTE (AREA (Complete Precipitation))

$$ACP = AIP + \sum_{n} ASV_n$$

where n is defined above.

COMPUTE (Maximum RATE (Inner Reference))

$$RIRmax = (RVP)\ (TSavgdif)$$

$$\bullet \quad \left[P2 + \frac{(P1-P2)(\pi(230)^2 - Min(ACP,AIPref))}{(\pi(230)^2 - ATCmin)} \right]$$

COMPUTE (First ABSOLUTE DIFFERENCE)

$$AD1 = |ACP - AIPref|$$

COMPUTE (Maximum ABSOLUTE DIFFERENCE)

$$ADmax = (RACmax)(TSavgdif)$$

COMPUTE (Maximum RATE (Inner Volumetric Precipitation))

$$\mathrm{RIVmax} = (\mathrm{RCR})(\mathrm{TSavgdif}) \bullet \left[\mathrm{P2} + \frac{(\mathrm{P1}-\mathrm{P2})(\pi(230)^2 - \mathrm{Min}(\mathrm{AIP},\mathrm{ACPref}))}{(\pi(230)^2 - \mathrm{ATCmin})} \right]$$

COMPUTE (Second ABSOLUTE DIFFERENCE)

$$\mathrm{AD2} = |\mathrm{AIP} - \mathrm{ACPref}|$$

COMPUTE (RATE (Range Corrected Precipitation))

$$\mathrm{RRC} = \mathrm{C01} + \mathrm{C02}(\mathrm{RSP}) + \mathrm{C03}\log(\mathrm{RSmid}/1\ \mathrm{km})$$

COMPUTE (RATE (1/4th LFM Grid Box))

Step 1

$$\mathrm{RGB} = \frac{\sum_n \mathrm{ASV}_n \ 10^{\mathrm{RSP}_n/10}}{\sum_n \mathrm{ASV}_n}$$

where;

> sum is over all n sample volumes in the RATE SCAN whose centers fall within the boundaries of the BOX (1/4 LFM Grid) under consideration and ASV is defined above.

Step 2

RGB(code) <---- RGB (mm/hr)

8 level code - categories to be specified later.

4.0 OUTPUTS

4.1 IDENTIFICATION

The FLAG (Zero Rate) is output by this algorithm.

Whenever the FLAG (Zero Rate) and the FLAG (Bad) are both clear, the RATE SCAN, a scan set of rainfall rate values in dBR, is the major output from this algorithm.

A flag for bad data (FLAG (Bad)) is output by this algorithm. This information will be added to SUPPLEMENTAL DATA.

RATE (1/4th LFM Grid Box) are output for each BOX (1/4 LFM Grid). This array is included in SUPPLEMENTAL DATA.

4.2 DISTRIBUTION

The RATE SCAN and FLAG (Zero Rate) are intended for input to the PRECIPITATION ACCUMULATION [019] algorithm.

RATEs (1/4 LFM Grid Box) are intended for input to the PRECIPITATION PRODUCTS [021] algorithm.

RATE SCANs and FLAG(Zero Rate) are intended for input to the FLASH FLOOD PRECIPITATION PROJECTION [030] algorithm.

5.0 INFERENCES

5.1 LIMITATIONS

This algorithm does not accurately account for snow which may have a significantly different Z-R relationship and range effect correction function.

5.2 FUTURE DEVELOPMENTS

A range effect correction to operate on the RATE SCAN values will be refined further. The range effect correction is made using an empirically derived range dependent correction factor. This procedure corrects for the long term effects of signal degradation due to beam attenuation and partial beam filling which, on the average, reduce the precipitation rate estimates at further ranges. One possibility being investigated may be to vary the range effect correction function coefficients as a function of precipitation characteristics.

Adaptation parameters will be "fine tuned" using actual NEXRAD data.

PRECIPITATION ACCUMULATION
ALGORITHM DESCRIPTION
NX-DR-03-019/29

MAJOR REVISIONS SINCE MAY 1984

Precipitation Accumulation (019)

1. All algorithms appearing in the May 1984 report have undergone the following changes:

   a. Editorial and typographical changes.

   b. Explicit declaration of data element precision.

   c. Renaming of data element names and symbols to achieve unique naming.

   d. Data Dictionary changes resulting from other changes.

1.0 PROLOGUE

1.1 FUNCTIONAL DESCRIPTION

The PRECIPITATION ACCUMULATION algorithm uses the previous and current precipitation rate (RATE SCAN) data sets output by the PRECIPITATION RATE [018] algorithm to estimate the accumulation during all or parts of the scan to scan period. Accumulation is in units of dBA, which is defined as 10 log [(accumulation)/1 mm]. The period accumulation scan(s) generated during the current pass of this algorithm plus those produced within the hourly period under consideration, are then used to estimate an hourly running total or a clock hour total accumulation scan. This hourly accumulation scan is input to the PRECIPITATION ADJUSTMENT [020] algorithm. The PRECIPITATION ACCUMULATION algorithm also checks the hourly accumulations for suspect values and modifies these under certain conditions.

The technique used to estimate the accumulation during the scan to scan period depends upon the time between scans. If the time between scans is not too large, a simple average precipitation rate is computed for the scan to scan period. This average is computed for each of the one degree by 2 km sample volumes which make up the scan. These averages are then multiplied by the time between scans to construct a period accumulation scan with a 1 degree by 2 km resolution, which gives the estimated scan to scan accumulation in dBA. This scan is comprised of 41,400 1 degree by 2 km sample volumes.

If the time between scans is too large to use simple averaging (equivalent to linear interpolation), the precipitation rates for each scan are used separately to compute accumulations for the beginning and ending parts of the scan to scan period. The remainder of the scan to scan period, centered midway between the two scans, is flagged as a missing period. In this case, two 1 degree by 2 km resolution period accumulation scans are constructed.

Next, the beginning and ending times for the hourly accumulation period are established. If a clock hour was passed during the scan to scan period, these times coincide with the beginning and ending of the most recently completed clock hour. If the ending TIME (Gage Accumulation) for the hourly accumulation required by the PRECIPITATION ADJUSTMENT [020] algorithm was passed during the scan to scan period, these times coincide with the beginning and end of the hour ending at the ending TIME (Gage Accumulation). Otherwise, for an hourly running total accumulation the time period extends backward from the current scan time to a time one hour earlier.

Weighting each period accumulation scan by the fraction of it which falls in the hourly accumulation period, a 1 degree by 2 km resolution hourly accumulation scan for the specified hourly period is constructed. However, if too much of the specified hourly period is not covered by period accumulation scans (e.g., is missing), no hourly accumulations are constructed and the processing stream continues with the PRECIPITATION ADJUSTMENT [020] alogrithm.

Finially, each hourly accumulation scan sample volume value is checked against a threshold to see if it is reasonable. If it is greater than the threshold, (i.e., an outlier) and the values of all neighboring sample volumes are below the threshold, an interpolated accumulation is computed. These changes are made in such a way that subsequent modifications to outliers are not affected by the changes to those previously identified.

1.2 SOURCE

The PRECIPITATION ACCUMULATION algorithm was developed by the Radar Hydrology Group of the National Weather Service's Hydrologic Research Laboratory. This algorithm has been based on experiences gained through the use of real-time rainfall estimation from the D/RADEX system, the GATE project, and other experimental projects, as well as an indepth analysis of ways which weather radar data could be better used for hydrometeorological purposes.

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1.3 PROCESSING ENVIRONMENT

This algorithm requires precipitation rate scans from both the previous and current outputs of the PRECIPITATION RATE [018] algorithm. Only scans flagged as good in the PRECIPITATION RATE [018] algorithm are used (i.e. previous scan means previous good scan). Zero rate scans (scans not actually generated but assumed to be RATE (Zero Precipitation) everywhere) can be good scans. The algorithm is sufficiently flexible so that it can provide accumulation information for as much of the scan-to-scan period as possible even when the time between scans is larger than 5 minutes. However, the error associated with the accumulation will grow rapidly as the time between scans increases. Therefore, in order to provide, to the maximum extent possible, uninterrupted precipitation record, the method used to save the previous precipitation rate scan must be safe, even from temporary system shutdowns and restarts.

Whenever the current precipitation rate scan is the first scan in a new clock hour, clock hour accumulations are computed instead of computing running hourly accumulations (note: the only difference between clock hour and running hourly accumulations are the starting and ending times for the one hour accumulation period). Since the time between scans may be large if a system problem occurs, the clock hour accumulation period could be set to begin up to 2 hours before the current scan time. In addition, missing periods must be taken into account so that hourly integration criteria can be checked. Therefore, all scan-to-scan period accumulation scans for periods ending any time after 1 hour prior to the previous scan time must be saved. The previous scan time is the last good scan collected prior to the current scan. The method used to save these period accumulation scans must be safe, even from temporary system shutdowns and restarts.

Generally rainfall rates or accumulations can be retained in two types of units. The more familiar linear units are mm (for accumulations) or mm/hr (for rates). Logarithmic units can also be used (dBA for accumulations, dBR for rates). There are trade-offs involved in the units chosen. The storage requiremints for the logarithmic units are approximately one-half that for linear units (about 8 bits/value as opposed to about 16 bit/value). However, several computations must be done in linear units which necessitates conversions from logarithmic to linear units (and vice versa) if logarithmic units are used. These conversions incur a penalty on CPU time. These algorithms are currently written in logarithmic units.

Wherever a power of 10 or base 10 logarithm is found in these algorithms a conversion from logarithmic units to linear units or vice versa is taking place. This conversion can be done by actually computing the powers and logarithms at each sample volume or through the use of a computation saving technique such as the use of a discrete conversion table or any other technique providing sufficient precision. The use of dBRs and dBAs is intended to reduce storage requirements while maintaining required precision at the small end of the scale. However, as long as the requested precision at the small end of the scale is maintained, some CPU time may be saved by keeping the data in linear (mm/hr or mm) units at the expense of increases in storage requirements. If the data are kept in units of mm/hr or mm the computational steps must be appropriately modified to remove the conversions which are no longer needed. The units used for external communications should be chosen on the basis of communications requirements (e.g., dBA's for the ARRAY PRODUCT (Digital Precipitation)) regardless of the units used for internal computations.

2.0 INPUTS

2.1 IDENTIFICATION

RATE SCAN = Precipitation rate data on a 1 degree by 2 km polar grid from 1 to 230 km, in dBR. A precision of at least 0.5 dBR and a dynamic range of at least -18 to 32 dBR are required (not generated for times when FLAG (Zero Rate) or when FLAG (Bad) are set).

average TIME (Scan) = The average scan time of the four elevation scans used to construct the HYBRID SCAN. This is a time of occurrence, not duration.

FLAG (Zero Rate) = A set or cleared flag for each average TIME (Scan) indicating, if set, that all precipitation rate values can be assumed to be equal to the RATE (Zero Precipitation).

maximum TIME (Interpolation) = The maximum period over which a period accumulation scan can be computed using two precipitation rate scans, in hours (approximately 0.5 hours).

minimum TIME (Period) = The minimum period of time during an hourly accumulation period for which ACCUMULATION SCAN (Period) data are required in order to estimate the hourly accumulation in hours (approximately 0.90 hours).

ACCUMULATION SCAN (Period) = Interpolated or extrapolated period precipitation accumulation data on a 1 degree by 2 km polar grid from 1 to 230 km, in dBA.

TIME (Last Precipitation Detected) = The time at which the Precipitation Detection support function last detected precipitation.

PRECIPITATION STATUS MESSAGE = An alphanumeric message which includes the radar ID, TIME(Stamp), current radar status, current operational mode, current scan strategy, TIME(Last Precipitation Detected), CATEGORY(Precipitation), number of gages in data base, and time since last update to the gage data base.

THRESHOLD (Hourly (Outlier) = The maximum hourly rainfall amount allowed in an hourly accumulation scan sample volume (26.0), in dBA. A precision of at least 0.5 dBA is required.

ending TIME (Gage Accumulation) = The time, each hour, when hourly radar and gage accumulations are required by the PRECIPITATION ADJUSTMENT [020] algorithm. A precision of at least 1/1200 hour is required.

ACCUMULATION (Zero = The hourly precipitation accumulation considered to be zero (-18), in dBA.

2.2 ACQUISITION

RATE SCANs and FLAG (Zero Rate) are obtained from the PRECIPITATION RATE [018] algorithm.

Average TIMEs (Scan) for each RATE SCAN are obtained from the PRECIPITATION PREPROCESSING [017] algorithm.

Maximum TIME (Interpolation) and minimum TIME (Period) are system adaptation parameters and are based on empirical/ theoretical studies.

ACCUMULATION SCANs (Period) are computed during PRECIPITATION ACCUMULATION algorithm passes and saved for periods ending any time after 1 hour prior to the previous average TIME (Scan). The previous average TIME (Scan) is the average scan time of the last good scan successfully collected prior to the current scan.

THRESHOLD (Hourly Outlier) is a seasonally dependent unit adaptation parameter based on empirical/theoretical studies.

PRECIPITATION STATUS MESSAGE including the TIME (Last Precipitation Detected) is obtained from the Precipitation Detection support function.

Ending TIME (Gage Accumulation) is a site adaptation parameter specified by the PRECIPITATION ADJUSTMENT [020] algorithm.

ACCUMULATION (Zero Hourly) is a system adaptation parameter.

3.0 PROCEDURE

3.1 ALGORITHM

```
BEGIN ALGORITHM (PRECIPITATION ACCUMULATION)

1.0  COMPUTE (average TIME (Scan) difference)
     Clear FLAG (Zero Scan-to-Scan).

2.0  IF (average TIME (Scan) difference is less than maximum
        TIME (Interpolation))
        THEN
        2.1  IF (Current FLAG (Zero Rate) set AND the
                previous FLAG (Zero Rate) set)
                THEN
                   COMPUTE (ACCUMULATION (Zero
                           Interpolated))
                   Set FLAG (Zero Scan-to-Scan).
                   Set all interpolated ACCUMULATION SCAN
                   (Period) values to ACCUMULATION (Zero
                   interpolated).
                ELSE
                   COMPUTE (Interpolated ACCUMULATION SCAN
                           (Period))
                   Set ACCUMULATION SCAN (Scan-to-Scan) to
                   interpolated ACCUMULATION SCAN (Period).
                   WRITE (ACCUMULATION SCAN (Scan-to-Scan))
             END IF
        ELSE
        2.2  COMPUTE (beginning TIME (Missing Period))
        2.3  COMPUTE (ending TIME (Missing Period))
        2.4  WRITE (TIME (Missing Period))
        2.5  IF (previous FLAG (Zero Rate) set)
                THEN
                   COMPUTE (ACCUMULATION (Zero
                           Extrapolated))
                   Set all forward extrapolated ACCUMULATION
                   SCAN (Period) values to ACCUMULATION
                   (Zero Extrapolated).
                ELSE
                   COMPUTE (forward extrapolated ACCUMULATION
                           SCAN (Period))
             END IF
        2.6  IF (current FLAG (Zero Rate) set)
                THEN
                   COMPUTE (ACCUMULATION (Zero
                           Extrapolated))
                   Set all backward extrapolated
                   ACCUMULATION SCAN (Period) values to
                   ACCUMULATION (Zero Extrapolated).
                ELSE
                   COMPUTE (backward extrapolated
                           ACCUMULATION SCAN (Period))
             END IF
```

```
      2.7  IF (last FLAG (Zero Rate) set AND current FLAG
                (Zero Rate) set)
                THEN
                   Set FLAG (Zero Scan-to-Scan).
                ELSE
                   COMPUTE (ACCUMULATION SCAN
                                (Scan-to-Scan))
                   WRITE (ACCUMULATION SCAN (Scan-to-Scan))
             END IF
     END IF

 3.0 WRITE (FLAG (Zero Scan-to-Scan))

 4.0 Replace ending TIME (Accumulation) with current average
     TIME (Scan).

 5.0 IF (End of clock hour occurred since the previous
        average TIME (Scan) and before or at the current
        average TIME (Scan))
        THEN
           Replace ending TIME (Accumulation) with the end
           time of the most recently completed clock hour.
     END IF

 6.0 IF (ending TIME (Gage Accumulation) has occurred since
        the previous average TIME (Scan) AND before or at
        the current average TIME (Scan))
        THEN
           Replace ending TIME (Accumulation) with the
           ending TIME (Gage Accumulation).
     END IF

 7.0 Beginning TIME (Accumulation) = Ending TIME
     (Accumulation) minus one hour.

 8.0 COMPUTE (total TIME (Period))

 9.0 Clear FLAG (No Hourly Accumulation)

10.0 IF (total TIME (Period) is greater than minimum TIME
        (Period))
        THEN
           Clear FLAG (Zero Hourly Accumulation).
           IF (TIME (Last Precipitation Detected) is before
              beginning TIME (Accumulation))
              THEN
                 Set FLAG (Zero Hourly Accumulation).
              ELSE
                 COMPUTE (ACCUMULATION SCAN (Hourly))
                 DO FOR ALL (SAMPLE VOLUMEs)
                IF (SAMPLE VOLUME value from ACCUMULATION
                   SCAN (Hourly) is greater than THRESHOLD
                   (Hourly Outlier) AND all eight adjoin-
                   ing SAMPLE VOLUME values are less
                   than the THRESHOLD (Hourly Outlier))
                   THEN
                      COMPUTE (interpolated ACCUMULATION
                              (Hourly)) for that SAMPLE
                              VOLUME.
                              Replace Accumulation SCAN
                              (Hourly) for that SAMPLE
                              VOLUME with interpolated
                              Accumulation (Hourly).
                              Keep count of the NUMBER
                              (Interpolated Accumulation
                              Outlier).
                END IF
              END DO
              WRITE (NUMBER (Interpolated Accumulation
                    Outlier))
              WRITE (ACCUMULATION SCAN (Hourly))
        END IF
        WRITE (FLAG (Zero Hourly Accumulation))
     ELSE
     Set FLAG (No Hourly Accumulation)
   END IF

11. WRITE (Flag (No Hourly Accumulation))

END ALGORITHM (PRECIPITATION ACCUMULATION)
```

3.2 COMPUTATION

3.2.1 NOTATION

TSavgdif = average TIME (Scan) difference, the difference in time at which scans were taken, in hours to the nearest 1/1200 hour.

TSavgcur = current average TIME (Scan), the average TIME (Scan) time of the current RATE SCAN (or implied zero RATE SCAN if FLAG (Zero Rate) set), to at least 1/1200 hour.

TSavepre = previous average TIME (Scan), the average TIME (Scan) of the last good RATE SCAN (or implied zero RATE SCAN if FLAG (Zero Rate) set), to at least 1/1200 hour.

AHint = interpolated ACCUMULATION (Hourly), the interpolated hourly radar precipitation accumulation using the eight neighboring sample volume accumulation values, in dBA. Precise to at least 0.5 dBA.

AZE = ACCUMULATION (Zero Extrapolated), the zero level for an extrapolated ACCUMULATION SCAN (Period), in dBA. A precision of at least 0.5 dBA and dynamic range of at least -29 to 26 dBA are required.

AZI = ACCUMULATION (Zero Interpolated), the zero level for an interpolated ACCUMULATION SCAN (Period), in dBA. A precision of at least 0.5 dBA and a dynamic range of at least -29 to 26 dBA are required.

ASP = ACCUMULATION SCAN (Period), interpolated or extrapolated period precipitation accumulation on a 1 degree by 2 km polar grid from 1 to 230 km, in dBA. A precision of at least 0.5 dBA and a dynamic range of at least -29 to 26 dBA are required.

FHA = FLAG (Zero Hourly Accumulation), a set or cleared flag indicating, if set, that all current ACCUMULATION SCAN (Hourly) values can be assumed to be equal to ACCUMULATION (Zero Hourly).

ASPint = interpolated ACCUMULATION SCAN (Period), the precipitation accumulations for the period from previous average TIME (Scan) to current average TIME (Scan) obtained by interpolation from the previous and current RATE SCANs, in dBA. Precise to at least 0.5 dBA.

ASPfwdext = forward extrapolated ACCUMULATION SCAN (Period), the precipitation accumulations for the period from previous average TIME (Scan) to beginning TIME (Missing Period) obtained by extrapolation from the previous RATE SCAN, in dBA. Precise to at least 0.5 dBA.

ASPbacext = backward extrapolated ACCUMULATION SCAN (Period), the precipitation accumulations for the period from ending TIME (Missing Period) to current average TIME (Scan) obtained by extrapolation from the current RATE SCAN, in dBA. Precise to at least 0.5 dBA.

RSPcur = current RATE SCAN, the current precipitation rate data on a 1 degree by 2 km polar grid from 1 to 230 km, in dBR. A precision of at least 0.5 dBR and a dynamic range of at least -18 to 32 dBR are required.

FNA = FLAG(No Hourly Accumulation), a set or cleared flag indicating, if set, that no hourly accumulations were computed for the hour ending at the current ending TIME (Accumulation).

FZS = FLAG (Zero Scan-to-Scan), a set or cleared flag indicating, if set, that all current ACCUMULATION SCAN (Scan-to-Scan) values can be assumed to be equal to Accumulation (Zero Interpolated).

RSPpre = previous RATE SCAN, the previous precipitation rate data on a 1 degree by 2 km polar grid from 1 to 230 km, in dBR. A precision of at least 0.5 dBR and a dynamic range of at least -18 to 32 dBR are required.

TMP = TIME (Missing Period), the beginning and ending times of any missing periods between the previous scan time and current scan time. Precise to 1/1200 hr.

TMPbeg = beginning TIME (Missing Period), the beginning times of any missing periods between the previous scan time and current scan time. Precise to 1/1200 hr.

TMPend = ending TIME (Missing Period), the ending times of any missing periods between the previous scan time and current scan time. Precise to 1/1200 hr.

TIPmax = maximum TIME (Interpolation), the maximum period over which a period accumulation scan can be computed using two precipitation rate scans, in hours. Approximately 0.5 hours with a precision of at least 1/60th hour is required.

TPE = TIME (Period), the beginning and ending times for all ACCUMULATION SCAN (Period) data which are available, in hours. Precise to 1/1200 hr.

WFP = WEIGHT FACTOR (Period Accumulation), the time between the beginning of a period and the end of a period which covers a particular ACCUMULATION SCAN (Period), in hours. Precise to 1/1200 hr.

TPEbeg = beginning TIME (Period), the beginning time for a particular ACCUMULATION SCAN (Period). Precise to 1/1200 hr.

TPEend = ending TIME (Period), the ending time for a particular ACCUMULATION SCAN (Period). Precise to 1/1200 hr.

TPEmin = minimum TIME (Period), the minimum period of time during an hourly accumulation period for which ACCUMULATION SCAN (Period) data are required in order to estimate the hourly accumulation, in hours. Precise to 1/60th hr. (approximately 0.90 hours).

ASS = ACCUMULATION SCAN(Scan-to-Scan), the total scan-to-scan accumulation data on a 1 degree by 2 kilometer polar grid from 1 to 230 kilometers. A precision of at least 0.5 dBA and dynamic range of at least -29 to 26 dBA are required. Includes the previous average TIME (Scan) and current average TIME (Scan).

TAbeg = beginning TIME (Accumulation), the beginning time of an ACCUMULATION SCAN (Hourly). Precise to 1/1200 hr.

TAend = ending TIME (Accumulation), the ending time of an ACCUMULATION SCAN (Hourly). Precise to 1/1200 hr.

ASH = ACCUMULATION SCAN (Hourly), the hourly radar precipitation accumulation data for an hourly running period or clock hour on a 1 degree by 2 kilometer polar grid from 1 to 230 kilometers. A precision of at least 0.5 dBA and a dynamic range of at least -18 to 32 dBA are required. Includes the beginning TIME (Accumulation) and ending TIME (Accumulation).

ACR = ACCUMULATION (Rainfall), the rainfall accumulation for a sample volume within a particular ACCUMULATION SCAN (Period), in millimeters. A precision of 0.01 millimeters and a dynamic range of 0 to 398 millimeters are required.

AZP = ACCUMULATION (Zero Period), the zero level for a particular ACCUMULATION SCAN (Period), in dBA. A precision of at least 0.5 dBA and a dynamic range of -29 dBA to 26 dBA are required.

AZH = ACCUMULATION (Zero Hourly), the hourly precipitation accumulation considered to be zero (-18), in dBA. Precise to 0.5 dBA.

NAO = NUMBER (Interpolated Accumulation Outliers), the number of hourly accumulation sample volumes that contained hourly outliers which could be removed by interpolation.

TLD = TIME (Last Precipitation Detected), the time at which the Precipitation Detection support function last detected precipitation. Precise to 1/1200 hr.

Note: Precision will be units specified unless otherwise stated.

3.2.2 SYMBOLIC FORMULAS

COMPUTE (average TIME (Scan) difference)

$$TSavgdif = (TSavgcur - TSavgpre)$$

COMPUTE (ACCUMULATION (Zero Interpolated))

$$AZI = 10.0 \log \left[(10^{AZH/10.0}) \bullet \left(TSavgdif\right) \right]$$

COMPUTE (interpolated ACCUMULATION SCAN (Period))

$$ASPint = 10.0 \log \left[\frac{TSavgdif(10^{RSPpre/10.0} + 10^{RSPcur/10.0})}{2.0} \right]$$

for ranges 1 to 229 by 2 and azimuths 0 to 359 by 1.

where, TSavgdif is defined above

and the quantities $10^{RSPpre/10.0}$ or $10^{RSPcur/10.0}$ are considered zero if the previous or current FLAG (Zero Rate) are set, respectively.

COMPUTE (beginning TIME (Missing Period))

$$TMPbeg = (TSavgpre + \frac{TIPmax}{2.0})$$

COMPUTE (ending TIME (Missing Period))

$$TMPend = (TSavgcur - \frac{TIPmax}{2.0})$$

TPEend = ending TIME (Period), the ending time for a particular ACCUMULATION SCAN (Period). Precise to 1/1200 hr.

TPEmin = minimum TIME (Period), the minimum period of time during an hourly accumulation period for which ACCUMULATION SCAN (Period) data are required in order to estimate the hourly accumulation, in hours. Precise to 1/60th hr. (approximately 0.90 hours).

ASS = ACCUMULATION SCAN(Scan-to-Scan), the total scan-to-scan accumulation data on a 1 degree by 2 kilometer polar grid from 1 to 230 kilometers. A precision of at least 0.5 dBA and dynamic range of at least -29 to 26 dBA are required. Includes the previous average TIME (Scan) and current average TIME (Scan).

TAbeg = beginning TIME (Accumulation), the beginning time of an ACCUMULATION SCAN (Hourly). Precise to 1/1200 hr.

TAend = ending TIME (Accumulation), the ending time of an ACCUMULATION SCAN (Hourly). Precise to 1/1200 hr.

ASH = ACCUMULATION SCAN (Hourly), the hourly radar precipitation accumulation data for an hourly running period or clock hour on a 1 degree by 2 kilometer polar grid from 1 to 230 kilometers. A precision of at least 0.5 dBA and a dynamic range of at least -18 to 32 dBA are required. Includes the beginning TIME (Accumulation) and ending TIME (Accumulation).

ACR = ACCUMULATION (Rainfall), the rainfall accumulation for a sample volume within a particular ACCUMULATION SCAN (Period), in millimeters. A precision of 0.01 millimeters and a dynamic range of 0 to 398 millimeters are required.

AZP = ACCUMULATION (Zero Period), the zero level for a particular ACCUMULATION SCAN (Period), in dBA. A precision of at least 0.5 dBA and a dynamic range of -29 dBA to 26 dBA are required.

AZH = ACCUMULATION (Zero Hourly), the hourly precipitation accumulation considered to be zero (-18), in dBA. Precise to 0.5 dBA.

NAO = NUMBER (Interpolated Accumulation Outliers), the number of hourly accumulation sample volumes that contained hourly outliers which could be removed by interpolation.

TLD = TIME (Last Precipitation Detected), the time at which the Precipitation Detection support function last detected precipitation. Precise to 1/1200 hr.

Note: Precision will be units specified unless otherwise stated.

3.2.2 SYMBOLIC FORMULAS

COMPUTE (average TIME (Scan) difference)

$$\text{TSavgdif} = (\text{TSavgcur} - \text{TSavgpre})$$

COMPUTE (ACCUMULATION (Zero Interpolated))

$$\text{AZI} = 10.0 \log \left[(10^{\text{AZH}/10.0}) \bullet \left(\text{TSavgdif}\right) \right]$$

COMPUTE (interpolated ACCUMULATION SCAN (Period))

$$\text{ASPint} = 10.0 \log \left[\frac{\text{TSavgdif}(10^{\text{RSPpre}/10.0} + 10^{\text{RSPcur}/10.0})}{2.0} \right]$$

for ranges 1 to 229 by 2 and azimuths 0 to 359 by 1.

where, TSavgdif is defined above

and the quantities $10^{\text{RSPpre}/10.0}$ or $10^{\text{RSPcur}/10.0}$ are considered zero if the previous or current FLAG (Zero Rate) are set, respectively.

COMPUTE (beginning TIME (Missing Period))

$$\text{TMPbeg} = (\text{TSavgpre} + \frac{\text{TIPmax}}{2.0})$$

COMPUTE (ending TIME (Missing Period))

$$\text{TMPend} = (\text{TSavgcur} - \frac{\text{TIPmax}}{2.0})$$

COMPUTE (ACCUMULATION (Zero Extrapolated))

$$AZE = 10.0 \log \left[(10^{AZH/10.0}) \bullet \left(\frac{TIPmax}{2.0} \right) \right]$$

Note: This computation is not data dependent; it depends only on AZH and TIPmax.

COMPUTE (forward extrapolated ACCUMULATION SCAN (Period))

$$ASPfwdext = 10.0 \log \left[\frac{TIPmax}{2.0} \left(10^{RSPpre/10.0} \right) \right]$$

for ranges 1 to 229 by 2 and azimuths 0 to 359 by 1.

COMPUTE (backward extrapolated ACCUMULATION SCAN (Period))

$$ASPbacext = 10.0 \log \left[\frac{TIPmax}{2.0} \left(10^{RSPcur/10.0} \right) \right]$$

for ranges 1 to 229 by 2 and azimuths 0 to 359 by 1.

Note: Time from TMPbeg to TMPend is to be flagged as a missing period.

COMPUTE (ACCUMULATION SCAN (Scan-to-Scan))

$$ASS = 10.0 \log \left[10^{ASPfwdext/10.0} + 10^{ASPbacext/10.0} \right]$$

for ranges 1 to 229 by 2 and azimuths 0 to 359 by 1.

COMPUTE (total TIME (Period))

$$TPE = \sum_{n} WFP_n$$

where,

sum is over all n ACCUMULATION SCAN (Period) which have end times (TPEend) after the beginning TIME (Accumulation).

$$WFP_n = MAX (0,(MIN(TPEend,TAend) - MAX(TPEbeg,TAbeg)))$$

COMPUTE (ACCUMULATION SCAN (Hourly))

$$ASH = 10.0 \log \left[MAX \left[10^{AZH/10}, \sum_{n} \frac{WFP_n}{TPEend_n - TPEbeg_n} \bullet ACR_n \right] \right]$$

where,

$$ACR_n = \begin{cases} 10^{ASP_n/10} & \text{if } ASP_n > AZP_n \\ 0 & \text{if } ASP_n \leq AZP_n \end{cases}$$

$$AZP_n = 10.0 \log \left[10^{AZH/10.0} (TPEend_n - TPEbeg_n) \right]$$

for ranges 1 to 229 by 2 and azimuths 0 to 359.
The summation and WFP_n are defined above.

Note: AZP_n is constant for each sample volume within an ACCUMULATION SCAN (Period).

COMPUTE (interpolated ACCUMULATION (Hourly))

$$AHint = 10.0 \log \left[\frac{\sum_{n=1}^{8} 10^{ASH_n/10.0}}{8.0} \right]$$

where, sum (n) is over all eight neighboring ACCUMULATION SCAN (Hourly) sample volumes.

4.0 OUTPUTS

4.1 IDENTIFICATION

The ACCUMULATION SCAN (Hourly) (including the beginning TIME (Accumulation) and ending TIME (Accumulation) is output unless the FLAG (Zero Hourly Accumulation) or FLAG (No Hourly Accumulation) is set. This scan contains an hourly running total or clock hour total precipitation accumulation scan set.

An ACCUMULATION SCAN (Scan-to-Scan) (including the previous average TIME (Scan) and current average TIME (Scan)) is output unless the FLAG (Zero Scan-to-Scan) is set.

A FLAG (Zero Scan-to-Scan), FLAG (Zero Hourly Accumulation), and FLAG (No Hourly Accumulation) are output.

Additionally, TIME (Missing Period), the beginning and ending times of any missing periods between the previous average TIME (Scan) and current average TIME (Scan) and NUMBER (Interpolated Accumulation Outliers), the number of outliers which were interpolated in the ACCUMULATION SCAN (Hourly), are included in SUPPLEMENTAL DATA.

4.2 DISTRIBUTION

The ACCUMULATION SCAN (Hourly), ending TIME (Accumulation), and ACCUMULATION SCAN (Scan-to-Scan) are input to the PRECIPITATION ADJUSTMENT [020] algorithm.

The FLAG (Zero Scan-to Scan), FLAG (Zero Hourly Accumulation), and FLAG (No Hourly Accumulation) are input to the PRECIPITATION ADJUSTMENT [020] algorithm and the PRECIPITATION PRODUCTS [021] algorithm.

The FLAG(Zero Scan-to-Scan) is output to the FLASH FLOOD PRECIPITATION PROJECTION [030] algorithm.

5.0 INFERENCES

5.1 LIMITATIONS

Missing periods of data will reduce the accuracy of the accumulations.

5.2 FUTURE DEVELOPMENTS

Parameter values will be "fine tuned" using actual NEXRAD data.

PRECIPITATION ADJUSTMENT

ALGORITHM DESCRIPTION

NX-DR-03-020/25

MAJOR REVISIONS SINCE MAY 1984

Precipitation Adjustment (020)

1. All algorithms appearing in the May 1984 report have undergone the following changes:

   a. Editorial and typographical changes.

   b. Explicit declaration of data element precision.

   c. Renaming of data element names and symbols to achieve unique naming.

   d. Data Dictionary changes resulting from other changes.

2. An error in the hourly rain-gage accumulation calculation was corrected.

3. To avoid division by zero, the bias calculation will not be performed when all radar measurements in the gage-radar pairs are zero.

4. A change has been made to remove gage-radar pairs when both measurements are less than 0.6 mm. This helps avoid noisy bias estimates.

5. The DURATIONs (Increment Report Overlap) has been corrected. Before this correction, sequential reports of rainfall accumulation were being interpreted as having temporal gaps.

6. Added ACCUMULATION (Zero Hourly) to the list of adaptable parameters.

1.0 PROLOGUE

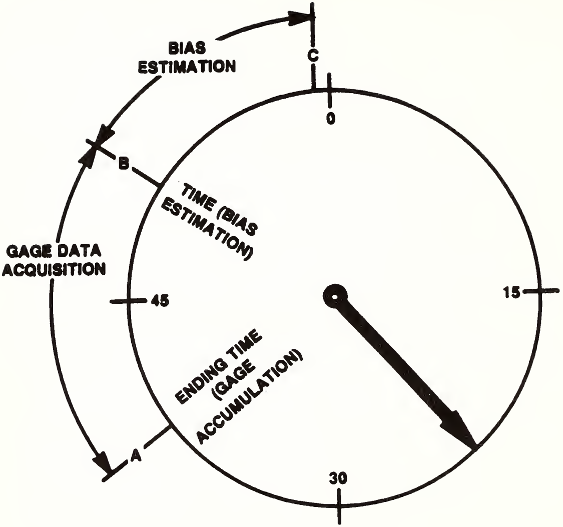
1.1 FUNCTIONAL DESCRIPTION

The PRECIPITATION ADJUSTMENT algorithm adjusts the hourly and scan to scan accumulations by multiplying by a bias. The algorithm uses hourly gage reports from the Gage Data Acquisition support function and an ACCUMULATION SCAN (Hourly) output by the PRECIPITATION ACCUMULATION [19] algorithm to generate comparable sets of gage and radar samples for specified hourly accumulation periods. These sets are used to update the existing bias every hour.

The timing of execution of the bias estimation procedure must allow for two timing delays: One is the time required to execute the procedure itself. Since the best possible estimate of the bias is desired at the end of each clock hour, the TIME (Bias Esimation) is set as close as possible to the clock hour, but in no case earlier than ten minutes before the clock hour. In other words, the bias update procedure must execute within an elapsed time of less than ten minutes.

The second time delay is required to acquire data from the rain gages. This time delay is defined by the polling, transmission, and formatting delays in the off-site systems which actually acquire data from the gages and by the delay in posting the data to the gage data base by the Gage Data Acquisition support function. The ending TIME (Gage Accumulation) is set earlier than the TIME (Bias Estimation) by an amount of time sufficient for this gage data acquisition process. Thus, the bias estimate actually is computed for a one hour period from one ending TIME (Gage Accumulation) to the next. The PRECIPITATION ACCUMULATION algorithm is required to produce an hourly accumulation scan for each ending TIME (Gage Accumulation). The timing execution is illustrated on Figure 1.

As soon as the TIME (Bias Estimation) is passed the gage observation vector and radar observation vector are generated. The gage observation vector contains the hourly gage accumulations from the gage reports. The radar observation vector contains the radar accumulation values corresponding to each value in the gage observation vector. These are computed based on the hourly accumulation scan sample volume value directly over the gage and at the eight surrounding sample volumes from the hourly accumulation scan ending at the ending TIME (Gage Accumulation). If, because of system problems, no hourly accumulation scan exists for the ending TIME (Gage Accumulation), no gage-radar sets are generated.



A — ENDING TIME (GAGE ACCUMULATION)

B — TIME (BIAS ESTIMATION)

C — NEW BIAS ESTIMATE AVAILABLE FOR HOUR ENDING AT A. THIS BIAS IS USED FROM TIME C ONWARD UNTIL THE BIAS IS AGAIN UPDATED.

Figure 1. Timing for bias estimation.

The number of elements in these vectors specifies the available number of gage-radar sets. If the hourly gage accumulation and corresponding radar accumulation are both less than 0.6 mm, the values are not added to the gage observation vector or radar observation vector (no gage-radar set is generated for these pairs).

The algorithm then produces an updated estimate of the radar bias factor for the specified hourly accumulation period and also a forecast of the radar bias factor for the next hour. Both the updated and forecast values of the radar bias have an associated estimation error variance which is also computed.

The bias estimation procedure is an implementation of a discrete Kalman filter. It presumes that the mean multiplicative bias follows a random walk process, i.e., the bias is equally likely to increase or decrease over the next hour. Based on this model, the best forecast for the next hour is simply the best current estimate. If enough gage-radar sets were generated for the most recently completed ending TIME (Gage Accumulation), the forecast from the last execution of the procedure is updated based on those data. The radar-gage sets are also used during each execution to estimate a measurement error covariance matrix, which (speaking in loose terms) measures the significance of the radar-gage sets as an estimator of the radar bias.

If not enough gage-radar sets for the ending TIME (Gage Accumulation) were generated, the forecast bias from the last hour becomes the new current bias value and the new forecast bias value is set equal to the current bias value. The estimation error variance also increases each hour by an additive system noise variance.

After the bias estimators have been propagated forward for an extended time period, they are reset to their long term values (presumably 1.0 for the bias) at a time when no significant precipitation has occurred during the past hour. This is done because the uncertainty of any bias estimate becomes too large to have any meaning after a certain amount of time without an update using gage-radar sets.

The current bias value is then used to update the most recent hourly accumulation scan and ACCUMULATION SCAN (Scan-to-scan) by simply adding the bias estimate (after conversion to dBA) to each value in the scans. (If accumulation data are in linear units, the correction is multiplicative.)

1.2 SOURCE

The PRECIPITATION ADJUSTMENT algorithm was developed by Dr. Edward R. Johnson of the Georgia Institute of Technology in cooperation with the Radar Hydrology Group of the National

Weather Service Hydrologic Research Laboratory. This algorithm is based on experience with a variety of Kalman filter applications and is currently being implemented for testing using D/RADEX data at the Pittsburgh site, and using PROFS data in a post-analysis mode.

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1.3 PROCESSING ENVIRONMENT

The bias estimation portion of the algorithm must be executed once each hour, using radar-gage sets which represent hourly accumulations for evenly spaced one hour time steps.

Therefore, the PRECIPITATION ADJUSTMENT algorithm requires one hour radar accumulations and gage accumulations for specific hourly periods. The time required to poll gages makes it impossible to obtain readings from all gages at exactly the beginning and end of the specified hourly period. Therefore, readings of gages before (if available), during, and after the specified hourly period from each gage are used to estimate the accumulation for exactly the specified hourly period. The specified hourly accumulation periods for the radar and gages will end the same time each hour at a particular site, but may vary from site to site depending on the time period normally required for gage data acquisition.

The rain gage data are acquired continuously by the Gage Data Acquisition support function which maintains a data base of gage reports. These reports are of two types: accumulator reports which give the total accumulation at a gage (mm) at a specified point in time and incremental reports which give the incremental accumulation at a gage (mm) for a specified duration at a specified time. The computation of hourly gage accumulation for the accumulator type reports is illustrated in Figure 2.

The computation of hourly gage accumulation for incremental reports is illustrated in Figure 3 where the vertical scale now is the precipitation rate (mm/hr), i.e., the accumulation from each report is an area on Figure 3.

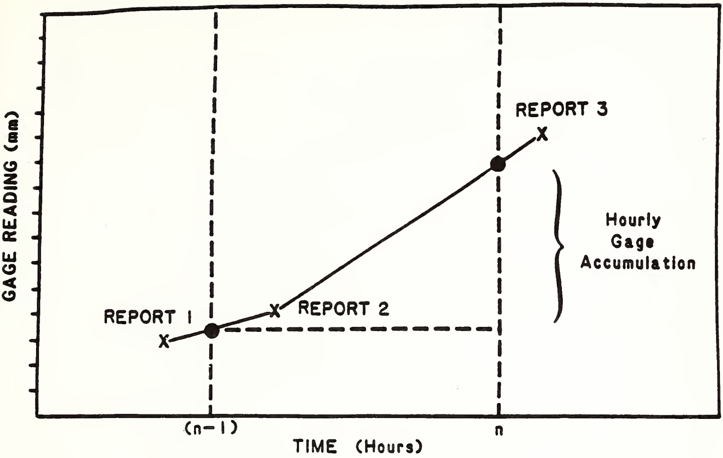

Figure 2 — Determination of an hourly gage accumulation for a specified hourly period from 3 gage readings of the accumulator type.

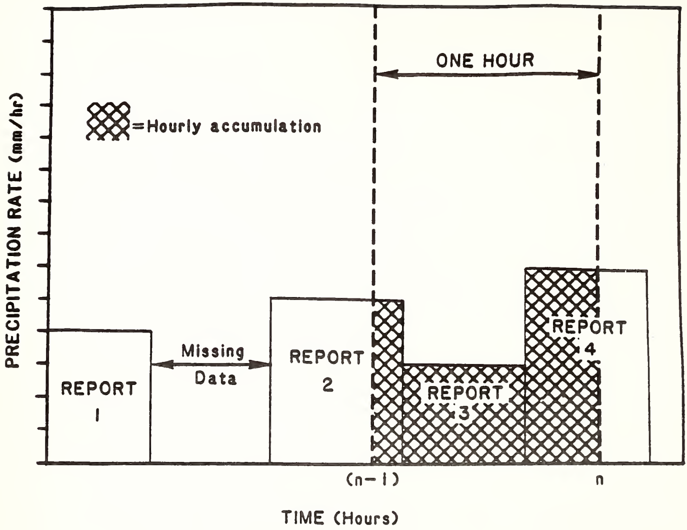

Figure 3 -- Determination of an hourly gage accumulation for a specified hourly period from incremental reports.

For several reasons the computation of hourly values from the gage reports is somewhat more complicated than the illustration of Figures 2 and 3. For accumulator reports, there is an upper limit (the THRESHOLD (Time Difference)) to the time difference between the ending TIME (Gage Accumulation) and the closest (in time) report. If no report is available within the THRESHOLD (Time Difference) of the ending TIME (Gage Accumulation) the estimate is considered too unreliable to be used, i.e., it is discarded.

A second problem arises from missing data. If no accumulator reports are available to bracket the ending TIME (Gage Accumulation) or if any of the hourly period has no incremental reports to cover it, then no estimate is possible.

It is possible that incremental reports will have variable durations, even overlapping durations, at a particular site. This complicates the gage precipitation estimates considerably.

Finally, the possibility of transmission errors, sensor errors, or other sources of error in the gage reports makes it necessary to include simple quality control procedures on the hourly gage estimates. First all hourly gage estimates below zero or above 400 mm are discarded. Then the mean and variance of the differences between hourly gage and radar estimates is computed and any gage-radar set with a difference greater than a threshold value (specified in terms of standard deviations) away from the mean difference is discarded.

Considering all of the above and the fact that precipitation must be detected (either by gage or radar) for a gage to appear in the gage-radar sets, it will be a relatively rare occurrence for all available gages to be included. Nevertheless, if more than 30 valid gage-radar sets are available, only the "first" 30 are used in the update procedure. The order is specified in the Gage Data Acquisition support function. This restriction serves to reduce the computational burden for the rare data-rich case.

Special care has been taken during algorithm development so that it will be computationally efficient and numerically stable. The algorithm should pose no numerical difficulties if all computations (including required matrix inversion) are in at least single precision (approximately a 6 decimal digit) floating point arithmetic.

Generally rainfall rates or accumulations can be retained in two types of units. The more familiar linear units are mm (for accumulations) or mm/hr (for rates). Logarithmic units can also be used (dBA for accumulations, dBR for rates). There are trade-offs involved in the units chosen. The storage requirements for the logarithmic units are approximately one-half that for linear units (about 8 bits/value as opposed to about 16 bits/value). However, several computations must be done in linear units which necessitates conversions from logarithmic to linear units (and vice versa) if logarithmic units are used. These conversions incur a penalty on CPU time. These algorithms are currently written in logarithmic units.

Wherever a power of 10 or base 10 logarithm is found in these algorithms a conversion from logarithmic units to linear units or vice versa is taking place. This conversion can be done by actually computing the powers and logarithms at each sample volume or through the use of a computation saving technique such as the use of a discrete conversion table or any other technique providing sufficient precision. The use of dBRs and dBAs is intended to reduce storage requirements while maintaining required precision at the small end of the scale. However, as long as the requested precision at the small end of the scale is maintained, some CPU time may be saved by keeping the data in linear (mm/hr or mm) units at the expense of increases in storage requirements. If the data are kept in units of mm/hr or mm the computational steps must be appropriately modified to remove the conversions which are no longer needed. The units used for external communications should be chosen on the basis of communications requirements (e.g. dBA's for the ARRAY) PRODUCT (Digital Precipitation)) regardless of the units used for internal computations.

This algorithm will be initiated on two different criteria. Whenever a scan is completed by the PRECIPITATION ACCUMULATION [020] algorithm, steps 2.0 through 5.0 of this algorithm must be executed to adjust the computed accumulation scans for the mean radar bias factor.

The actual bias computation contained in steps 1.0 through 1.5 should be executed on a wall clock basis, regardless of the processing of other radar data, when the TIME (Bias Estimation) is passed. These parts of the algorithm need not be initiated exactly at the TIME (Bias Estimation), but any delays in initiating the bias computation must be accounted for in setting the TIME (Bias Estimation). Therefore the sum o the initiation delay and the actual bias computation time must not exceed the 10 minute limit established above. If an alternative initiation process tied to scan completion or some other criterion rather than the wall clock is adopted, but the same 10 minute limit can be assured, then the alternative will be acceptable.

2.0 INPUTS

2.1 IDENTIFICATION

ending TIME (Gage Accumulation) = The ending time of the ACCUMULATION SCAN (Hourly) and the computed hourly gage values from which the gage-radar sets are generated. Will be the same time each hour for a particular radar site.

TIME (Bias Estimation) = The time each hour which signals the initiation of the BIAS computation process. A precision of at least 1/60 hour is required.

ending TIME (Accumulation) = The ending time of an ACCUMULATION SCAN (Hourly).

THRESHOLD (Number of Sets) = The minimum number of GAGE-RADAR SETs for which covariance estimation is allowed (2-10).

reset BIAS = The reset (long term mean) multiplicative factor that adjusts for the radar bias when compared to surface precipitation measurements (presumably 1). A precision of at least 0.01 is required.

reset MEAN SQUARE ERROR = The reset (long term mean) Mean Square Error (M.S.E.) value used when the M.S.E. has been propagated for an extended time. A precision of at least 0.01 is required.

maximum MEAN SQUARE ERROR = The maximum MEAN SQUARE ERROR (M.S.E.) allowed (0.8).

GAGE REPORTs (Accumulator) = Reported values of accumulation in mm at each gage and time of occurrence (to the nearest 1/60 hour).

GAGE REPORTs (Incremental) = Reported values of incremental accumulation in mm, increment duration (hours to the nearest 1/60 hour) and time of occurrence (to the nearest 1/60 hour).

THRESHOLD (Time Difference) = Maximum time (in hours to the nearest 1/60 hour) to the closest GAGE REPORT (Accumulator) for a valid estimate of accumulation at the ending TIME (Gage Accumulation). A precision of at least 1/60 hour is required.

maximum TIME (Propagation) = Maximum time that the BIAS estimates are allowed to propagate before being reset, in hours. A precision of at least 0.5 hour is required.

CATEGORY(Precipitation) = The precipitation category currently in effect.

Category	Meaning
0	No precipitation detected during the past hour
1	Significant precipitation detected during the past hour
2	Light precipitation detected during the past hour

PRECIPITATION STATUS MESSAGE = An alphanumeric message which includes the radar ID, TIME(Stamp), current radar status, current operational mode, current scan strategy, TIME (Last Precipitation Detected), CATEGORY(Precipitation), number of gages in a data base, and time since last update to the gage data base.

FLAG (Zero Hourly Accumulation) = A set or cleared flag indicating, if set, that all current ACCUMULATION SCAN (Hourly) values can be assumed to be equal to ACCUMULATION (Zero Hourly).

FLAG (Zero Scan-to-Scan) = A set or cleared flag indicating, if set, that all current ACCUMULATION SCAN (Scan-to-Scan) values can be assumed to be equal to ACCUMULATION (Zero Interpolated).

FLAG (No Hourly Accumulation) = A set or cleared flag indicating, if set, that no hourly accumulations were computed for the hour ending at the current ending TIME (Accumulation).

SYSTEM NOISE = The estimated mean square error of the drift in the radar BIAS from one hour to the next (0.05).

ACCUMULATION SCAN (Hourly) = The hourly radar precipitation accumulation data for an hourly running period or clock hour on a 1 degree by 2 kilometer polar grid from 1 to 230 kilometers, in dBA. A precision of at least 0.5 dBA and a dynamic range of at least -18 to 32 dBA are required. Includes the beginning TIME (Accumulation) and ending TIME (Accumulation).

ACCUMULATION SCAN (Scan-to-Scan) = The total scan-to-scan accumulation data on a 1 degree by 2 kilometer polar grid from 1 to 230 kilometers for the period from the previous time to the current time, in dBA. A precision of at least 0.5 dBA and a dynamic range of at least -29 to 26 dBA are required. Includes the previous average TIME (Scan) and current average TIME (Scan).

VARIANCE ADJUSTMENT FACTOR = An adjustment factor used to insure that the MATRIX (Measurement Covariance) is positive-definite; a dimensionless number less than 1.0 and greater than or equal to 0 (estimated to be 0.5).

THRESHOLD (Gage Discard) = Threshold value of the normalized gage-radar difference to discard the gage data value. A dimensionless number. A precision of at least 0.1 is required.

DISTANCE MATRIX = The distance from each gage to every other gage, in kilometers.

ACCUMULATION (Zero Hourly) = The hourly precipitation accumulation considered to be zero, in dBA.

2.2 ACQUISITION

The following are unit adaptation parameters:

THRESHOLD (Time Difference)
ending TIME (Gage Accumulation)
THRESHOLD (Number of Sets)
maximum TIME (Propagation)
SYSTEM NOISE
VARIANCE ADJUSTMENT FACTOR
reset BIAS
reset MEAN SQUARE ERROR
maximum MEAN SQUARE ERROR
THRESHOLD (Gage Discard)
TIME (Bias Estimation)

The following are obtained from the PRECIPITATION ACCUMULATION [019] algorithm:

ACCUMULATION SCAN (Scan-to-Scan)
ending TIME (Accumulation)
ACCUMULATION SCAN (Hourly)
FLAG (Zero Hourly Accumulation)
FLAG (Zero Scan-to-Scan)
FLAG (No Hourly Accumulation)

The following are obtained from the data base maintained by the Gage Data Acquisition support algorithm:

GAGE REPORT (Accumulator)
GAGE REPORT (Incremental)
DISTANCE (Between Gages)

The ACCUMULATION (Zero Hourly) is a system adaptation parameter.

PRECIPITATION STATUS MESSAGE and the CATEGORY(Precipitation) is obtained from the Precipitation Detection support function.

3.0 PROCEDURE

3.1 ALGORITHM

```
BEGIN ALGORITHM (PRECIPITATION ADJUSTMENT)

1.0  IF (Time is past TIME (Bias Estimation) AND the
        previous TIME (Bias Update) is before TIME (Bias
        Estimation))
        THEN
        1.1  Replace the previous BIAS with the forecast
             BIAS.
             Replace the previous MEAN SQUARE ERROR with the
             forecast MEAN SQUARE ERROR.
             Replace the value of the previous TIME (Bias
             Update) with the current time.
        1.2  IF (ACCUMULATION SCAN (Hourly) with an ending
                TIME (Accumulation) equal to ending TIME
                (Gage Accumulation) exists)
                THEN
                1.2.1  DO FOR ALL (Gages)
                          IF (Any GAGE REPORTs (Accumulator)
                             are available for this gage)
                             THEN
                                COMPUTE (TIMES (Closest
                                        Accumulator))
                                COMPUTE (maximum TIME (Gage
                                        Interpolation))
                                IF (Maximum TIME (Gage
                                   Interpolation) is less than
                                   or equal to THRESHOLD
                                   (Time Difference))
                                   THEN
                                      COMPUTE (accumulator
                                              GAGE ACCUMULA-
                                              TION (Estimated
                                              Hourly))
                                   ELSE
                                      There is no estimate
                                      for this gage.
                                END IF
                             ELSE
                                COMPUTE (DURATIONS (Increment
                                        Report Overlap))
                                COMPUTE (FLAG (Missing Data))
                                IF (FLAG (Missing Data) is
                                   not set)
                                   THEN
                                      COMPUTE (incremental
                                              GAGE ACCUMULA-
                                              TION (Estimated
                                              Hourly))
```

```
                    ELSE
                       No estimate for this
                       gage.
                 END IF
              END IF
           END DO
1.2.2      DO FOR ALL (GAGE ACCUMULATIONs
                      (Estimated Hourly))
              IF (Gage accumulation is less than
                 0 or more than 400 mm)
                 THEN
                    Delete GAGE ACCUMULATION
                    (Estimated Hourly).
                 ELSE
                    COMPUTE (RADAR OBSERVATION)
              END IF

           END DO

1.2.3      IF (The number of GAGE ACCUMULATIONs
              (Estimated Hourly) is greater than
              THRESHOLD (Number of Sets))
              THEN
                 COMPUTE (MEAN GAGE-RADAR
                         DIFFERENCE)
                 COMPUTE (STANDARD DEVIATION
                         GAGE-RADAR DIFFERENCE)
                 DO FOR ALL (GAGE ACCUMULATIONs
                            (Estimated Hourly))
                    COMPUTE (GAGE RADAR DIFFERENCE
                            (Normalized))
                    IF (GAGE RADAR DIFFERENCE
                       (Normalized) is greater
                       than THRESHOLD (Gage
                       Discard))
                       THEN

                          Delete GAGE ACCUMULATION
                          (Estimated Hourly).
                    END IF
                 END DO
           END IF
1.2.4      DO FOR ALL (GAGE ACCUMULATIONs
                      (Estimated Hourly))
              IF (RADAR OBSERVATION AND GAGE
                 ACCUMULATION (Estimated Hourly)
                 not both less than 0.6 mm)
```

```
                THEN
                   Include RADAR OBSERVATION in
                   the VECTOR (Radar Observation).
                   Include GAGE ACCUMULATION
                   (Estimated Hourly) in the
                   VECTOR (Gage Observation).
                   RADAR OBSERVATION and GAGE
                   ACCUMULATION (Estimated
                   Hourly) are thus paired into
                   a GAGE-RADAR SET.  Keep track of
                   which gage is stored in each ele-
                   ment of VECTOR(Gage Observation).
                   Keep count of the number of GAGE-
                   RADAR SETS.
             END IF
          END DO
          IF (All RADAR OBSERVATIONs are equal to 0)
             THEN
                The number of GAGE-RADAR sets is set
                to 0.
          END IF
      ELSE
         The number of GAGE-RADAR SETs is set to 0.
    END IF
1.3 IF (The number of GAGE-RADAR SETs is greater
      than or equal to THRESHOLD (Number of Sets))
      THEN
      1.3.1  COMPUTE (INNOVATIONS)
      1.3.2  COMPUTE (INNOVATIONS (Variance
                     Parameter))
      1.3.3  COMPUTE (INNOVATIONS (Decay Parameter))
      1.3.4  COMPUTE (INNOVATIONS (Second Variance
                     Parameter))
      1.3.5  COMPUTE (OBSERVATION (Variance
                     Parameter))
      1.3.6  COMPUTE (OBSERVATION (Decay Parameter))
      1.3.7  COMPUTE (OBSERVATION (Second Variance
                     Parameter))
      1.3.8  COMPUTE (VARIANCE INFLATOR)
      1.3.9  IF (Number of GAGE-RADAR SETs greater
                than 30)
                THEN (Delete all but first 30
                     entries)
             END IF
      1.3.10 COMPUTE (MATRIX (Measurement
                     Covariance))
      1.3.11 COMPUTE (MATRIC (Gain))
      1.3.12 COMPUTE (BIAS)
      1.3.13 COMPUTE (MEAN SQUARE ERROR)
      1.3.14 COMPUTE (forecast BIAS)
      1.3.15 COMPUTE (forecast MEAN SQUARE ERROR)
      1.3.16 Replace previous TIME (Bias Compute)
             with the ending TIME (Gage Accumula-
             tion).
```

```
                 ELSE
                 1.3.17 COMPUTE (TIME (Difference #2))
                 1.3.18 IF (TIME (Difference #2) is greater
                             than maximum TIME (Propagation) AND
                             CATEGORY(Precipitation) indicates no
                             precipitation in the previous hour)
                             THEN
                             1.3.18.1  Replace the current BIAS
                                       with the reset BIAS.
                             1.3.18.2  Replace the current MEAN
                                       SQUARE ERROR with the reset
                                       MEAN SQUARE ERROR.
                             1.3.18.3  Replace the forecast BIAS
                                       with reset BIAS.
                             1.3.18.4  Replace the forecast MEAN
                                       SQUARE ERROR with reset
                                       MEAN SQUARE ERROR.
                             ELSE
                             1.3.18.5  Replace the BIAS with
                                       forecast BIAS.
                             1.3.18.6  Replace the MEAN SQUARE
                                       ERROR with forecast MEAN
                                       SQUARE ERROR.
                             1.3.18.7  COMPUTE (MEAN SQUARE ERROR
                                               (Propagated
                                                Forecast))
                             1.3.18.8  Replace the forecast MEAN
                                       SQUARE ERROR with the MEAN
                                       SQUARE ERROR (Propagated
                                       Forecast).
                      END IF
            END IF
       1.4  WRITE (BIAS)
       1.5  WRITE (MEAN SQUARE ERROR)
       END IF

2.0  IF (FLAG (No Hourly Accumulation) not set
        AND FLAG (Zero Hourly Accumulation) not set)
        THEN
           2.1  COMPUTE (adjusted ACCUMULATION SCAN (Hourly))
           2.2  WRITE (adjusted ACCUMULATION SCAN (Hourly))
     END IF

3.0  IF FLAG (Zero Scan-to-Scan) not set)
         THEN
         3.1  COMPUTE (adjusted ACCUMULATION SCAN
                       (Scan-to-Scan))
         3.2  WRITE (adjusted ACCUMULATION SCAN
                     (Scan-to-Scan))
     END IF

END ALGORITHM (PRECIPITATION ADJUSTMENT)
```

3.2 COMPUTATION

3.2.1 NOTATION

TGAend = ending TIME (Gage Accumulation), the ending time of the ACCUMULATION SCAN (Hourly) and the computed hourly gage values from which the gage-radar sets are generated. Will be the same time each hour for a particular radar site.

TGAbeg = beginning TIME (Gage Accumulation), one hour before the ending TIME (Gage Accumulation).

TAbeg = beginning TIME (Accumulation), the beginning time of an ACCUMULATION SCAN (Hourly). Precise to 1/1200 hr.

TAend = ending TIME (Accumulation), the ending time of an ACCUMULATION SCAN (Hourly). Precise to 1/1200 hr.

MSEmax = maximum MEAN SQUARE ERROR, the maximum Mean Square Error (M.S.E.) allowed (0.8).

ROB = RADAR OBSERVATION, the radar observation used as part of the gage-radar set by a Kalman filtering procedure. Based on the hourly radar accumulations at the nine sample volumes closest to the gage, in mm.

Bpre = previous BIAS, the previous multiplicative factor that adjusts for the radar bias when compared to surface precipitation measurements.

MSEpre = previous MEAN SQUARE ERROR, the Mean Square Error (M.S.E.) of the previous BIAS value.

Bcur = current BIAS, the current multiplicative factor that adjusts for the radar bias when compared to surface precipitation measurements.

MSEcur = current MEAN SQUARE ERROR, the Mean Square Error (M.S.E.) of the current BIAS value.

Bfor = forecasted BIAS, the forecasted multiplicative factor that adjusts for the radar bias when compared to surface precipitation measurements.

MSEfor = forecasted MEAN SQUARE ERROR, the Mean Square Error (M.S.E.) of the forecasted BIAS value.

MSEprofor = MEAN SQUARE ERROR (Propagated Forecast), the sum of the previous Mean Square Error and SYSTEM NOISE.

VGO = VECTOR (Gage Observation), the computed hourly gage accumulations for the hour ending with the ending TIME (Gage Accumulation) obtained from the gage reports, in millimeters.

GRA = GAGE REPORT (Accumulator), reported values of accumulation in mm at each gage and time of occurrence. Precise to 0.01 mm.

GRI = GAGE REPORT (Incremental), reported values of incremental accumulation in mm, increment duration and time occurrence. Precise to 0.01 mm.

GA = GAGE ACCUMULATION (Estimated Hourly), the estimated hourly accumulation in mm at a gage for the one hour period ending at TAend.

GAinc = Incremental GAGE ACCUMULATION (Estimated Hourly), the estimated hourly accumulation in mm at a gage for the one hour period ending at TAend computed from incremental gage reports.

GAacc = Accumulator GAGE ACCUMULATION (Estimated Hourly), the estimated hourly accumulation in mm at a gage for the one hour period ending at TAend computed from accumulator gage reports.

TG = TIME (Gage Report), the time of a particular accumulator gage report.

TZA = TIME (Closest Accumulator), the set of times TGbefbeg, TGaftbeg, TGbefend, TGaftend defining the times of occurrence of GAGE REPORTs (Accumulator) closest in time to TGAbeg and TGAend.

TGbefbeg = before-beginning TIME (Gage Report), the TIME (Gage Report) which is before and closest to TGAbeg.

TGaftbeg = after-beginning TIME (Gage Report), the TIME (Gage Report) which is after and closest to TGAbeg.

TGbefend = before-ending TIME (Gage Report), the TIME (Gage Report) which is before and closest to TGAend.

TGaftend = after-ending TIME (Gage Report), the TIME (Gage Report) which is after and closest to TGAend.

TGImax = Maximum TIME (Gage Interpolation), the maximum time difference in hours from the TIMEs (Gage Report) closest to TAbeg and TAend, respectively.

TBCpre = previous TIME (Bias Compute), the time that the BIAS was last computed using gage values.

TIA = TIME (Increment Report Accuracy), twice the accuracy of the Beginning TIME (Increment Report) or ending TIME (Increment Report), whichever is the least accurate, in hours to the nearest 1/1200 hr.

TIbeg = Beginning TIME (Increment Report), the time of the start of a particular incremental gage report.

TIend = Ending TIME (Increment Report), the time of the end of a particular incremental gage report.

DIO = DURATION (Incremental Report Overlap), the duration of the portion of a particular incremental gage report that overlaps the hourly accumulation period, in hours to the nearest 1/1200 hour.

T2 = TIME (Difference #2), the length of time, in hours to the nearest 1/60 hour, that the BIAS has been propagated forward without update using gage data.

GR = GAGE-RADAR DIFFERENCE, the difference in accumulation between a GAGE ACCUMULATION (Estimated Hourly) and the corresponding radar accumulation, in millimeters.

MGR = MEAN GAGE RADAR DIFFERENCE, the mean of the gage-radar differences in precipitation accumulation, in millimeters. Precise to 0.1 mm.

SGR = STANDARD DEVIATION GAGE-RADAR DIFFERENCE, the standard deviation of the gage-radar difference in precipitation accumulation, in millimeters. Precise to 0.1 mm.

GRN = GAGE-RADAR DIFFERENCE (Normalized), the normalized difference in accumulation between an hourly gage report and the corresponding radar accumulation, dimensionless.

GRS = GAGE-RADAR SET, the combination of associated pairs of hourly radar accumulations and hourly gage accumulations.

VRO = VECTOR (Radar Observation), the hourly radar accumulation for the hour ending at the ending TIME (Gage Accumulation). Each value is based on the hourly accumulation scan values of the sample volume directly over the gage and the eight surrounding sample volumes, in mm.

MXC = MATRIX (Covariance Measurement), a symmetric measurement error covariance matrix.

DG = DISTANCE (Between Gages), the distance between gages in the VECTOR(Gage Observation), in kilometers. Precise to 0.1 km.

INN = INNOVATIONS, a vector of the differences between the VECTOR (Gage Observation) and the VECTOR (Radar Observation) multiplied by the previous BIAS.

INNavg = average INNOVATIONS, the average of all INNOVATIONS, in mm.

MXG = MATRIX (Gain), a vector (1 x N matrix) giving the gain values - the multiplicative factors giving the influence of each innovation on the updated bias.

IV = INNOVATIONS (Variance Parameter), a variance parameter of an isotropic exponential-form covariance function of the difference between the adjusted radar accumulation and the gage accumulation, in mm^2.

ISV = INNOVATIONS (Second Variance Parameter), a second variance parameter which allows for variance at zero distance in addition to the exponential decay portion of an isotropic exponential-form covariance function of the difference between the adjusted radar accumulation and the gage accumulation, in mm^2.

IDP = INNOVATIONS (Decay Parameter), a decay parameter of an isotropic exponential-form covariance function of the difference between the adjusted radar accumulation and the gage accumulation, in 1/km. A precision of at least 4 decimal digits over a range of at least 10^{10} to 10^{-10} power is required.

OV = OBSERVATION (Variance Parameter), a variance parameter of the function that improves the mathematical properties of a matrix composed of the outer product of the VECTOR (Radar Observation), in mm^2.

OSV = OBSERVATION (Second Variance Parameter), a second variance parameter of the function that improves the mathematical properties of a matrix composed of the outer product of the VECTOR (Radar Observation), in mm^2.

OD = OBSERVATION (Decay Parameter), a decay parameter of a function that improves the mathematical properties of a matrix composed of the outer product of the VECTOR (Radar Observation), in 1/km. A precision of at least 4 decimal digits over a range of at least 10^{10} to 10^{-10} power is required.

FMD = FLAG (Missing Data), a flag indicating missing incremental gage report data during the hourly accumulation period.

VI = VARIANCE INFLATOR, a value that reduces the measurement error estimates to account for imperfect prediction of the radar bias itself.

VAF = VARIANCE ADJUSTMENT FACTOR, an adjustment factor used to insure that MATRIX (Measurement Covariance) is positive-definite; a dimensionless number less than 1.0 and greater than or equal to 0. (Estimated to be 0.5).

SYS = SYSTEM NOISE, the estimated mean square error of the drift in the radar BIAS from one hour to the next (0.5).

TBUpre = previous TIME (Bias Update), the time at which the BIAS was last updated, to at least the nearest 1/60 hour.

ASH = ACCUMULATION SCAN (Hourly), the hourly radar precipitation accumulation data for an hourly running period or clock hour on a 1 degree by 2 kilometer polar grid from 1 to 230 kilometers, in dBA. A precision of at least 0.5 dBA and a dynamic range of at least -18 to 32 dBA are required. Includes the beginning TIME (Accumulation) and ending TIME (Accumulation).

ASHadj = adjusted ACCUMULATION SCAN (hourly), adjusted hourly radar precipitation accumulation data for an hourly running period or clock hour on a 1 degree by 2 kilometer polar grid from 1 to 230 km, in dBA. This data has been adjusted for the mean field bias. A precision of at least 0.5 dBA and dynamic range of at least -18 to 32 dBA are required. Includes the beginning TIME (Accumulation) and ending TIME (Accumulation).

TSavgcur = average current TIME (Scan), the average TIME (Scan) of the current RATE SCAN (or implied zero RATE SCAN if FLAG (Zero Rate) is set) to at least 1/1200 hour.

TSavgpre = average previous TIME (Scan), the average TIME (Scan) of the last good RATE SCAN (or implied zero RATE SCAN if FLAG (Zero Rate) is set) to at least 1/1200 hour.

FNA = FLAG(No Hourly Accumulation), a set or cleared flag indicating, if set, that no hourly accumulations were computed for the hour ending at the current ending TIME (Accumulation).

AZH = ACCUMULATION (Zero Hourly), the hourly precipitation accumulation considered to be zero (-18), in dBA. Precise to 0.5 dBA.

AZL = ACCUMULATION (Zero Level), the zero level for the ACCUMULATION SCAN (Scan-to-Scan), in dBA. A precision of at least 0.5 dBA and range of at least -29 to 26 dBA are required.

FNA = FLAG(Zero Hourly Accumulation), a set or cleared flag indicating, if set, that all current ACCUMULATION SCAN(Hourly) values can be assumed to be equal to ACCUMULATION(Zero Hourly).

FZS = FLAG(Zero Scan-To-Scan), a set or cleared flag indicating, if set, that all current ACCUMULATION SCAN (Scan-to-Scan) values can be assumed to be equal to ACCUMULATION(Zero Interpolated).

ASS = ACCUMULATION SCAN (Scan-to-Scan), the total scan-to-scan accumulation data on a 1 degree by 2 kilometer polar grid from 1 to 230 kilometers for the period from the previous time to the current time, in dBA. A precision of at least 0.5 dBA and a dynamic range of at least -29 to 26 dBA are required. Includes the previous average TIME (Scan) and current average TIME (Scan).

ASSadj = adjusted ACCUMULATION SCAN (Scan-to-Scan), total scan-to-scan accumulation data on a 1 degreee by 2 km polar grid from 1 to 230 km (in dBA). This data has been adjusted for the estimated mean field bias. A precision of at least 0.5 dBA and dynamic range of at least -29 to 26 dBA are required. Includes the previous average TIME (Scan) and current average TIME (Scan).

NOTE: All times require a precision of at least 1/1200 hr unless otherwise stated. All variables with units of mm and mm^2 require a precision of at least 0.1 mm and 0.1 mm^2, unless otherwise stated. All computations must be done in at least single precision (approximately a 6 decimal digit) floating point arithmetic.

3.2.2 SYMBOLIC FORMULAS

COMPUTE (TIMEs (Closest Accumulator))

$$TGbefbeg = TGAbeg - \min_{TG} (TGAbeg - TG)$$

such that $TG \leq TGAbeg$
(i.e., the value of TG that minimizes
(TGAbeg - TG) subject to the given constraint)

$$TGaftbeg = \min_{TG} (TG - TGAbeg) + TGAbeg$$

such that $TGAbeg \leq TG$

$$TGbefend = TGAend - \min_{TG} (TGAend - TG)$$

such that $TG \leq TGAend$

$$TGaftend = \min_{TG} (TG - TGAend) + TGAend$$

such that $TGAend \leq TG$

COMPUTE (Maximum TIME (Gage Interpolation))

$$TGImax = Max(Min(TGAbeg-TGbefbeg, TGaftbeg-TGAbeg),$$

$$Min(TGAend-TGbefend, TGaftend-TGAend))$$

Note: If any of the values TGbefbeg, TGaftbeg, TGbefend, TGaftend are undefined because no gage reports exist which satisfy the given constraints in their computation, then set TGImax to a value greater than THRESHOLD (Time Difference).

COMPUTE (Accumulator GAGE ACCUMULATION (Estimated Hourly))

GAacc =

$$\left[GRAbefend + \frac{(TGAend-TGbefend)(GRAaftend-GRAbefend)}{(TGaftend - TGbefend)}\right]$$

$$- \left[GRAbefbeg + \frac{(TGAbeg-TGbefbeg)(GRAaftbeg-GRAbefbeg)}{(TGaftbeg - TGbefbeg)}\right]$$

Notes: (1) The notation GRAbefend refers to the value of GRA at the time TGbefend, etc.

(2) If TGaftend is identical to TGbefend then the second term on the right hand side above is zero.

(3) If TGaftbeg is identical to TGbefbeg then the fourth term on the right hand side above is zero.

COMPUTE (DURATIONs (Increment Report Overlap))

```
IF (($TIend_n$ - $TIbeg_n$ ) $\leq$ 1.25)
    THEN
    $DIO_n$ = MAX(0,(MIN(TGAend,$TIend_n$) - MAX(TGAbeg, $TIBEG_n$)))
    ELSE
    $DIO_n$ = 0
END IF
```

where n is over all available incremental gage reports for a particular gage.

```
COMPUTE (FLAG (Missing Data))

SET (FLAG (Missing Data))

$T_1$ = TGAbeg

$T_2$ = TGAend
DO FOR ALL (n incremental gage reports with $DIO_n$
           not equal to zero)

   DO FOR ALL (n incremental gage reports with $DIO_n$
              not equal to zero)

      IF $TIbeg_n \leq T_1 + TIA$  THEN $T_1 = MAX (T_1, TIend_n)$

      IF $TIend_n \geq T_2 + TIA$  THEN $T_2 = MIN (T_2, TIbeg_n)$

   END DO

   IF ($T_1 \geq T_2$) THEN clear (FLAG (Missing Data))

                    END COMPUTE

END DO

END COMPUTE
```

Note: (1) The "double" DO FOR ALL loop is required because the interior loop is only guaranteed to find one report each pass which will modify the value of T_1 or T_2. The computation can be ended as soon as the FLAG (Missing Data) is cleared.

(2) For purposes of estimating timing of this computation, a maximum size of 10 for the number of incremental gage reports with non-zero DIO_n can be assumed - the most likely value is two or three.

COMPUTE (Incremental GAGE ACCUMULATION (Estimated Hourly)

$$\text{GAinc} = \frac{\sum_n \left[\frac{GRI_n}{TIend_n - TIbeg_n} \right] \left[\frac{DIO_n}{TIend_n - TIbeg_n} \right]}{\sum_n \left[\frac{DIO_n}{TIend_n - TIbeg_n} \right]}$$

where the summations are over all available incremental gage reports for a particular gage with DIO_n not equal to zero.

COMPUTE (RADAR OBSERVATION)

$$Q5_n = 10^{ASH_n (TGAbeg,\ TGAend)/10}$$

where the index n is over the 9 radar sample volumes closest to the mth raingage.

```
IF (MAX ($Q5_n$) is greater than $GA_m$ AND
   MIN ($Q5_n$) is less than $GA_m$)
   THEN
      $ROB_m = GA_m$
   ELSE
      $ROB_m = Q5_n$ such that $|Q5_n - GA_m|$ is a minimum for the mth
      gage.
END IF
```

This allows for two major possibilities:

(1) misnavigation of the radar sample volumes or the raingage location.

(2) rainfall drifting from the elevation observed by the radar to the ground.

COMPUTE (MEAN GAGE-RADAR DIFFERENCE)

$$MGR = \frac{1}{N} \sum (GA_n - ROB_n)$$

where (GA - ROB) = GR and N is the number of existing GAGE ACCUMULATIONs (Estimated Hourly).

COMPUTE (STANDARD DEVIATION GAGE-RADAR DIFFERENCE)

$$SRG = \left[\frac{1}{N-1} \sum_n (GA_n - ROB_n - MGR)^2 \right]^{1/2}$$

where N is the number of existing GAGE ACCUMULATIONs (Estimated Hourly).

COMPUTE (GAGE-RADAR DIFFERENCE (Normalized))

$$GRN = \frac{|GA - ROB - MGR|}{SGR}$$

COMPUTE (INNOVATIONS)

$INN_n = VGO_n - (VRO_n\ (Bpre))$

where n is set to 1 through the number of gage-radar pairs.

COMPUTE (INNOVATIONS (Variance Parameter))

Step 1 - Compute INNavg and IV

$$INNavg = \frac{1}{N} \sum INN_n$$

$$IV = \frac{1}{N} \sum (INN_n - INNavg)^2$$

where N is the number of gage-radar sets.

Step 2 - Form the lists $Q2_m$ and $Q1_m$ from 1 to M where,

$$M = \frac{N\ (N-1)}{2}$$

$Q1_m$ = set of values DG_{nL}, the distance from gage n to gage L in VECTOR (Gage Observation), where $n \neq L$, $n > L$

$Q2_m$ = set of values $(INN_n - INNavg) \times (INN_L - INNavg)$

where $n \neq L$ (corresponding to Q1), $n > L$

In other words, the upper triangular portion of the matrix of values DG_{nL}, not including diagonal terms.

Then take natural log of Q2:

$$Q2 = \begin{cases} Ln\ (Q2), & Q2 > 0.0 \\ -10.00, & Q2 \leq 0.0 \end{cases}$$

Step 3 - Estimate IDP and ISV

COMPUTE (INNOVATIONS (Decay Parameter))

$$IDP = \frac{\sum Q1_m \; Q2_m - [(\sum Q1_m)(\sum Q2_m)]/M}{\sum (Q1_m)^2 - [\sum (Q1_m)]^2/M}$$

where, summations are from m=1 to m=M

COMPUTE (INNOVATIONS (Second Variance Parameter))

$$ISV = \exp\left[\frac{\sum Q2_m}{M} - IDP \frac{\sum Q1_m}{M}\right]$$

where, summations are from 1 to M

Step 4 - Validity test

If $IV \geq ISV$ and $IDP < 0$ then this computation is completed. Otherwise, contimue with Step 5 below.
Step 5 - Re-estimate parameters

a) Add to lists Q1 and Q2 all values where $n = L$, using same procedure as described in Step 2 above. The new value of M is:

$$M = \frac{N\,(N + 1)}{2}$$

In other words, add the diagonal elements to the lists.

b) Re-estimate IDP and ISV as in Step 3 above.

Step 6 - Final Validity Test

If $IV < ISV$ or $IDP \geq 0$ then set $ISV = 0$

COMPUTE (OBSERVATIONS (Variance Parameters))

Step 1 - Form the list $Q2_m$ and $Q1_m$ from 1 to M

where,

$$M = \frac{N\,(N - 1)}{2}$$

$Q1_m$ = set of values DG_{nL}, the distance from gage n to gage L in VECTOR (Gage Observation), where $n \neq L$, $n > L$

$Q2_m$ = set of values $(VRO_n)(VRO_L)$

where $n \neq L$ (corresponding to $Q1_m$), $n > L$

Then take natural log of $Q2_m$:

$$Q2 = \begin{cases} \mathrm{Ln}\ (Q2_m),\ Q2_m > 0.0 \\ -10.0,\ Q2 \leq 0.0 \end{cases}$$

Step 2, Estimate OV.

$$OV = \frac{1}{N} \left[\sum (VRO_n)^2 \right]$$

where, summation is for n from 1 to N, number of GAGE-RADAR sets.

Step 3 - Estimate OSV and OD

COMPUTE (OBSERVATIONS (Decay Parameter))

$$OD = \frac{\sum Q1_m\ Q2_m - [(\sum Q1_m)(\sum Q2_m)]/M}{\sum (Q1_m)^2 - [\sum (Q1_m)]^2/M}$$

where, summations are from 1 to M.

COMPUTE (OBSERVATIONS (Second Variance Parameter))

$$OSV = \exp \left[\frac{\sum Q2_m}{M} - OD \frac{\sum Q1_m}{M} \right]$$

where, summations are from 1 to M.

Step 4 - Validity test.

If $OV \geq OSV$ and $OD < 0$ then this computation is completed. Otherwise, continue with step 5 below.

Step 5 - Reestimate Parameters

a) Add to lists Q1 and Q2 all values where n = L, using same procedures as described in Step 1 above. The new value of M is:

$$M = \frac{N\ (N + 1)}{2}$$

b) Re-estimate OD and OSV as in Step 3 above.

Step 6 - Final validity test.

If $OV < OSV$ or $OD \geq 0$ then set $OSV = 0$.

COMPUTE (VARIANCE INFLATOR)

$$VI = MIN\ [MSEpre,\ VAF\ (\frac{IV}{OV})]$$

COMPUTE (MATRIX (Measurement Covariance))

If $ISV = 0$ set $OSV = 0$

IF $OSV = 0$ set $ISV = 0$.

$$MXC_{nL} = ISV\ exp\ [(IDP)\ (DG_{nL})] + Q3_{nL}(IV - ISV)$$
$$- VI\ [OSV\ exp\ [OD\ DG_{nL}] + Q3_{nL}\ (OV - OSV)]$$

where,

indicies n and L range from 1 to N (N=Number of gage-radar sets (N x N symmetric matrix)).

$$Q3_{nL} = \begin{cases} 1, & \text{if } n = L \\ 0, & \text{if } n \neq L \end{cases}$$

finally, if any $MXC_{nL} < 0$, set it to 0.

COMPUTE (MATRIX (Gain))

Step 1 - Construct intermediate matrix Q4 (N x N).

$$Q4_{nL} = (MSEpre)(VRO_n)(VRO_L) + MXC_{nL}$$

where n=1 to N, L=1 to N.

Step 2 - Invert matrix Q4. Note that Q4 is symmetric and positive definite by its construction.

The notation $Q4^{-1}_{nL}$ is the nLth element of the inverse of Q4, not $(\frac{1}{Q4_{nL}})$

Step 3 - Gain computation. Note that the gain is actually a (1 x N) matrix with elements MXG_n.

$$MXG_n = MSEpre \sum_{L=1}^{N} \left[(VRO_L)\ (Q4^{-1}_{nL}) \right]$$

for n=1 to N.

COMPUTE (BIAS)

$$Bcur = Bpre + \sum MXG_n\ INN_n$$

where, summation is from 1 to N.

COMPUTE (MEAN SQUARE ERROR)

$$MSEcur = (1 - \sum MXG_n\ ROB_n)\ MSEpre$$

where, summation is from 1 to N.

COMPUTE (forecast BIAS)

Bfor = Bcur

COMPUTE (forecast MEAN SQUARE ERROR)

MSEfor = Min (MSEmax, MSEcur + SYS)

COMPUTE (TIME (Difference #2))

$$T2 = |TGAend - TBC_{pre}|$$

COMPUTE (MEAN SQUARE ERROR (Propagated Forecast))

MSEprofor = Min (MSEmax, MSEpre + SYS)

COMPUTE (adjusted ACCUMULATION SCAN (Hourly))

$$\begin{aligned} ASHadj &= ASH + 10\ Log[Bcur],\ \text{if } ASH > AZH \\ &= ASH,\ \text{if } ASH \leq AZH \end{aligned}$$

for all precipitation rate sample volume values.

COMPUTE (adjusted ACCUMULATION SCAN (Scan-to-Scan))

$$\begin{aligned} \text{ASSadj} &= \text{ASS} + 10 \text{ Log[Bcur]}, \text{ if ASS} > \text{AZL} \\ &= \text{ASS}, \text{ if ASS} \leq \text{AZL} \end{aligned}$$

for all precipitation rate sample volume values, where

$$\text{AZL} = 10 \text{ Log}\left[(10^{\text{AZH}/10})(\text{TSavgcur} - \text{TSavgpre})\right]$$

4.0 OUTPUTS

4.1 IDENTIFICATION

Whenever neither the FLAG (No Hourly Accumulation) nor the FLAG (Zero Hourly Accumulation) are set the adjusted ACCUMULATION SCAN (Hourly) (including the beginning TIME (Accumulation) and ending TIME (Accumulation)) is output. This scan contains an hourly running total or clock hour total precipitation accumulation scan set which has been adjusted using the current BIAS value.

Whenever the FLAG (Zero Scan-to-Scan) is not set the adjusted ACCUMULATION SCAN (Scan-to-Scan) which includes the previous average TIME (Scan) and current average TIME (Scan) is output. This contains the total scan-to-scan precipitation accumulation scan set which has been adjusted using the current BIAS value.

Additionally, the current values of the BIAS and MEAN SQUARE ERROR are included in SUPPLEMENTAL DATA.

4.2 DISTRIBUTION

The ending TIME (Gage Accumulation) is specified for the PRECIPITATION ACCUMULATION [019] algorithm.

The current BIAS and adjusted ACCUMULATION SCAN (Scan-to-Scan) is specified for the FLASH FLOOD PRECIPITATION PROJECTION [030] algorithm.

All other outputs are intended for input to the PRECIPITATION PRODUCTS [021] algorithm.

5.0 INFERENCES

5.1 LIMITATIONS

In order to update the bias estimate using gage data at any hour, this algorithm requires that at least THRESHOLD (Number of Sets) gages have precipitation during the hour. Several times this many gages must report data in order for the bias adjustment to be computed with sufficient frequency, since precipitation does not usually cover the entire area of radar coverage. Frozen hydrometeors may result in inaccurate gage measurements.

5.2 FUTURE DEVELOPMENTS

More sophisticated filtering procedures, particularly to estimate the system noise, are under investigation at this time. Refinements for snow situations will also be investigated in the future.

PRECIPITATION PRODUCTS

ALGORITHM DESCRIPTION

NX-DR-03-021/22

MAJOR REVISIONS SINCE MAY 1984

Precipitation Products (021)

1. All algorithms appearing in the May 1984 report have undergone the following changes:

    a. Editorial and typographical changes.

    b. Explicit declaration of data element precision.

    c. Renaming of data element names and symbols to achieve unique naming.

    d. Data Dictionary changes resulting from other changes.

2. Added ACCUMULATION (Zero Hourly) to the list of adaptable parameters.

1.0 PROLOGUE

1.1 FUNCTIONAL DESCRIPTION

The PRECIPITATION PRODUCTS [021] algorithm uses the adjusted ACCUMULATION SCAN (Hourly) and the adjusted ACCUMULATION SCAN (Scan-to-Scan) output by the PRECIPITATION ADJUSTMENT [020] algorithm and other outputs to produce a set of precipitation products. The products generated are: (1) an hourly running total or clock hour accumulation on both a 1/40th Limited Fine Mesh (LFM) rectangular (approximately 4 km by 4 km) grid and a 2 km by 2 km resolution grid (2) a three hour total accumulation; and (3) a storm total accumulation. The latter two products are on a 2 km by 2 km resolution grid. The 2 km by 2 km resolution products are intended primarily for graphical display while the 1/40th LFM grid product is an array product intended primarily for transmission and numerical use at external computer facilities.

The hourly running totals or clock hour totals on the 1/40th LFM grid are obtained by determining the mean, after conversion into absolute units (mm), of all adjusted ACCUMULATION SCAN (Hourly) sample volumes whose polar coordinate centers fall within each 1/40th LFM grid box. At the far ranges where no sample volume centers fall inside a box, the sample volume value at the sample volume whose center is closest to the center of the grid box becomes the value at the grid box. Annotations are automatically added to identify the product and to provide information related to how the data used to generate this product were processed.

Next, the hourly running totals or clock hour totals on the 2 km by 2 km grid are determined using the same approach used for 1/40th LFM grid boxes above. The data are then scaled to 16 levels for use as a display and annotations are added automatically to produce the 2 km by 2 km PRODUCT (Hourly Precipitation).

At a frequency of up to once per hour, the three clock hour totals on the 2 km by 2 km grid are computed by summing the available individual clock hour totals for the past three hours. At least two of the three hours of data must be available and missing periods should be noted. The data are then scaled to 16 accumulation levels for use as a display, and annotations are added automatically to produce the 2 km by 2 km PRODUCT (Three Hour Precipitation).

Lastly, the storm total (total precipitation since the last one hour break in significant precipitation) on the 2 km by 2 km grid is generated whenever certain scan-to-scan accumulation parameters are exceeded. It is then updated using each adjusted ACCUMULATION SCAN (Scan-to-Scan) received until being reset after a one hour break in significant precipitation. The data is then scaled to 16 levels for use as a display and annotations are added automatically to produce the new 2 km by 2 km PRODUCT (Storm Total Precipitation).

1.2 SOURCE

The PRECIPITATION PRODUCTS algorithm was developed by the Radar Hydrology Group of the National Weather Service's Hydrologic Research Laboratory. This algorithm has been based on experiences gained through the use of real-time rainfall estimation from the D/RADEX system, the GATE project, and other experimental projects as well as an in-depth analysis of ways with which weather radar data could be better used for hydrometeorological purposes.

Ahnert, P.R., M.D. Hudlow, and E.R. Johnson, 1984: Validation of the "on-site" Precipitation Processing System for NEXRAD. Preprints, 22nd Radar Meteor. Conf., AMS, Boston, Mass.

Ahnert, P.R., M.D. Hudlow, E.R. Johnson, D.R. Greene, and M.R. Dias, 1983: Proposed "on-site" precipitation processing system for NEXRAD. Preprints, 21st Radar Meteor. Conf., AMS, Boston, Mass.

Hudlow, M.D., D.R. Greene, P.R. Ahnert, W.F. Krajewski, T.R. Sivaramakrishnan, M.R. Dias, and E.R. Johnson, 1983: Proposed off-site precipitation processing system for NEXRAD. Preprints, 21st Radar Meteor. Conf., AMS, Boston, Mass.

1.3 PROCESSING ENVIRONMENT

The ARRAY PRODUCT (Digital Precipitation) on the 1/40th LFM grid will provide hourly running total or clock hour total precipitation accumulation estimates in a digital array format (not a display compatible format) to support hydrometeorological requirements for numerical use of precipitation data in computers external to the NEXRAD RPG. In addition to the precipitation array data, an extensive set of annotations (IDENTIFIER INFORMATION and SUPPLEMENTAL DATA) will be included automatically as part of this product. This information is intended for use in higher level (regional/national) processing to identify certain characteristics about the data up to that point in the processing stream. It will be used as part of the information for accomplishing more discriminating quality control functions at the higher level of processing. Because some users may not require the full set of annotations, the option must exist to request the product with abbreviated or complete annotations. Abbreviated annotations should include only the product identification information and a list of missing periods. Also for certain applications it will be useful to obtain selected annotations (SUPPLEMENTAL DATA) including the RATE (1/4th LFM Grid Box) without the hourly precipitation totals themselves. This option must also be provided.

The Limited Fine Mesh (LFM) grid is a rectangular grid commonly used by the National Weather Service which is based on a polar stereographic projection. An LFM grid box represents an area whose size and shape varies with latitude. Therefore the size and shape of the grid boxes will vary slightly over the area covered by the radar and even more from radar to radar (3.5 to 4.5 km over the conterminous U.S. for the 1/40th LFM grid. The 1/40th LFM grid boxes used here are defined to have 1/40th LFM grid points as their centers and a mesh length of 4.7625 km at 60° N latitude. The information required to generate the grid for each site are the latitude and longitude of the radar, the mesh length at 60° N latitude (the standard latitude), and the standard longitude (105° W).

In order to cover the radar umbrella out to 230 km even at the lower latitudes of the conterminous United States, a 131 by 131 array of 1/40th LFM grid boxes will be required. This array will always be 131 by 131 regardless of the latitude of the site. This grid should be positioned in such a way that the radar site falls within the grid box (66,66). The ARRAY PRODUCT (Digital Precipitation) must be compacted (e.g., elimination of all 0 rows, run length encoding of rows) to reduce storage and especially communications loadings. Compaction must be done in such a way that the source 131 by 131 array can be reconstructed with the use of nominal computer resources. The 1/4th LFM area-averaged precipitation rate data (8 coded precipitation rate levels) for each scan used to generate the ARRAY PRODUCT (Digital Precipitation) will normally be automatically included as part of the annotations (SUPPLEMENTAL DATA) to the ARRAY PRODUCT (Digital Precipitation). The values for the 13 by 13 1/4th LFM grid were computed by the PRECIPITATION RATE [018] algorithm. These must be compacted subject to the constraints specified above.

The 2 km by 2 km PRODUCT (Three Hour Precipitation) uses the 2 km by 2 km PRECIPITATION TOTALs (Hourly) for the last three clock hours. In order to provide these products on a consistent basis, the method used to save the 2 km by 2 km PRECIPITATION TOTALs (Hourly) must be safe, even from temporary system shutdowns and restarts.

The 2 km by 2 km PRODUCT (Storm Total Precipitation) uses the previous set of 2 km by 2 km PRECIPITATION TOTAL (Storm). Again, the method used to save these data must be safe, even from temporary shutdowns and restarts.

Generally rainfall rates or accumulations can be retained in two types of units. The more familiar linear units are mm (for accumulations) or mm/hr (for rates). Logarithmic units can also be used (dBA for accumulations, dBR for rates). There are trade-offs involved in the units chosen. The storage requirements for the logarithmic units are approximately one-half that for linear units (about 8 bits/value as opposed to about 16 bits/value). However, several computations must be done in linear units which necessitates conversions from logarithmic to linear units (and vice versa) if logarithmic units are used. These conversions incur a penalty on CPU time. These algorithms are currently written in logarithmic units.

Whenever a power of 10 or base 10 logarithm is found in these algorithms a conversion from logarithmic units to linear units or vice versa is taking place. This conversion can be done by actually computing the powers and logarithms at each sample volume or through the use of a computation saving technique such as the use of a discrete conversion table or any other technique providing sufficient precision. The use of dBRs and dBAs is intended to reduce storage requirements while maintaining required precision at the small end of the scale. However, as long as the requested precision at the small end of the scale is maintained, some CPU time may be saved by keeping the data in linear (mm/hr or mm) units at the expense of increases in storage requirements. If the data are kept in units of mm/hr or mm the computational steps must be appropriately modified to remove the conversions which are no longer needed. The units used for external communications should be chosen on the basis of communications requirements (e.g. dBA's for the ARRAY PRODUCT (Digital Precipitation)) regardless of the units used for internal computations.

2.0 INPUTS

2.1 IDENTIFICATION

CATEGORY (Precipitation) = The precipitation category currently in effect.

CATEGORY	MEANING
0	No precipitation detected during the past hour
1	Significant precipitation detected during the past hour
2	Light precipitation detected during the past hour

TIME (Stamp) = The time at which the Precipitation Detection support function was last executed. A precision of at least 1/1200 hour is required.

PRECIPITATION STATUS MESSAGE = An alphanumeric message which includes the radar ID, TIME(Stamp), current radar status, current operational mode, current scan strategy, TIME(Last Precipitation Detected), CATEGORY(Precipitation), number of gages in data base, and time since last update to the gage data base.

TIME (Last Precipitation Detected) = The time at which the Precipitation Detection support function last detected precipitation. A precision of at least 1/1200 hour is required.

FLAG (Zero Scan-to-Scan) = A set or cleared flag indicating, if set, that all current ACCUMULATION SCAN (Scan-to-Scan) values can be assumed to be equal to ACCUMULATION (Zero Interpolated).

FLAG (Zero Hourly Accumulation) = A set or cleared flag indicating, if set, that all current ACCUMULATION SCAN (Hourly) values can be assumed to be equal to ACCUMULATION (Zero Hourly).

BOX (1/40th LFM Grid) = Rectangular grid box centered on 1/40th LFM grid points. At 60 degrees N the mesh length is 4.7625 km. Specifies the Scan's sample volumes whose centers fall within each grid box. If none, the sample volume whose center is closest to the center of the grid box is specified. Grid boxes whose centers are more than 230 km from the radar are not assigned any sample volumes.

RATE (1/4th LFM Grid Box) = Area-average rate (8 level coded value) in each 1/4 LFM grid square. A 13 by 13 grid of values for each RATE SCAN used in constructing the hourly accumulations.

FLAG (No Hourly Accumulation) = A set or cleared flag indicating, if set, that no hourly accumulations were computed for the hour ending at the current ending TIME (Accumulation).

adjusted ACCUMULATION SCAN (Hourly) = Adjusted hourly radar precipitation accumulation data for an hourly running period or clock hour on a 1 degree by 2 km polar grid from 1 to 230 km, in dBA. This data has been adjusted for the mean field bias. A precision of at least 0.5 dBA and dynamic range of at least -18 to 32 dBA are required. Includes the beginning TIME (Accumulation) and ending TIME (Accumulation).

SUPPLEMENTAL DATA = A set of data which will be included as annotations to the four precipitation products.

IDENTIFIER INFORMATION = Consists of annotations such as the radar I.D., product name, time (beginning and ending), date and missing period times. The times must be in hours and minutes GMT (Greenwich Mean Time).

BOX (2 km x 2 km Grid) = These are square grid boxes which are 2 km on a side and cover ranges from 0 to 230 km. Specifies the 1 degree by 2 km accumulation scan sample volumes whose centers fall within each grid box. If none, the sample volume whose center is closest to the center of the grid box is specified. Grid boxes whose centers are more than 230 km from the radar are not assigned any sample volumes.

TIMES (Three Hour Product Generator) = A list of times for which 2 km x 2 km PRODUCTs (Three Hour Precipitation) should be generated, in hours, up to once per hour (0-23 inclusive).

adjusted ACCUMULATION SCAN (Scan-to-Scan) = Total scan-to-scan accumulation data on a 1 degree by 2 km polar grid from 1 to 230 km, in dBA. This data has been adjusted for the estimated mean field bias. A precision of at least 0.5 dBA and dynamic range of at least -29 to 26 dBA are required. Includes the previous average TIME (Scan) and current average TIME (Scan).

ACCUMULATION (Zero Hourly) = The hourly precipitation accumulation considered to be zero, in dBA.

2.2 ACQUISITION

BOX (1/40th LFM Grid) is a unit adaptation parameter file which is automatically generated given the latitude and longitude of the site, mesh length at 60° N (4.7625 km), and the reference longitude (105° W).

Adjusted ACCUMULATION SCAN (Hourly) data are obtained from the PRECIPITATION ADJUSTMENT [020] algorithm.

SUPPLEMENTAL DATA are obtained from a unit adaptation parameter file and assembled from other algorithms within the precipitation processing system.

IDENTIFIER INFORMATION are obtained from a unit adaptation parameter file, assembled from other algorithms within the precipitation processing system (e.g. PRECIPITATION PREPROCESSING [017]), and obtained from system status and calibration files.

BOX (2 km x 2 km Grid) is a system adaptation parameter file which is automatically generated.

TIMES (Three Hour Product Generator) are unit adaptation parameters.

Adjusted ACCUMULATION SCAN (Scan-to-Scan) data are obtained from the PRECIPITATION ADJUSTMENT [020] algorithm.

TIME (Stamp), PRECIPITATION STATUS MESSAGE, CATEGORY (Precipitation), and TIME (Last Precipitation Detected) are obtained from the Precipitation Detection support function.

FLAG (Zero Scan-to-Scan), FLAG (Zero Hourly Accumulation) and FLAG (No Hourly Accumulation) are obtained from the PRECIPITATION ACCUMULATION [019] algorithm.

ACCUMULATION (Zero Hourly) is a system adaptation parameter.

RATEs (1/4 LFM Grid Box) are obtained from the PRECIPITATION RATE [018] algorithm.

3.0 PROCEDURE

3.1 ALGORITHM

```
BEGIN ALGORITHM (PRECIPITATION PRODUCTS)

1.0  IF (FLAG (No Hourly Accumulation) not set)
        THEN
     1.1  IF (FLAG (Zero Hourly Accumulation) set)
             THEN
                Set all ARRAY TOTALs (Digital
                Precipitation) to ACCUMULATION (Zero
                Hourly).
             ELSE
                DO FOR ALL (BOX (1/40th LFM Grid))
                   COMPUTE (ARRAY TOTAL (Digital
                            Precipitation) elements)
                END DO
          END IF
     1.2  Combine ARRAY TOTAL (Digital Precipitation) and
          the RATEs (1/4 LFM Grid Box) with the appropriate
          SUPPLEMENTAL DATA and IDENTIFIER INFORMATION to
          produce the ARRAY PRODUCT (Digital Precipitation).
     1.3  WRITE (ARRAY PRODUCT (Digital Precipitation))
     1.4  IF (FLAG (Zero Hourly Accumulation) set)
             THEN
                Set all PRECIPITATION TOTALs (Hourly) to
                ACCUMULATION (Zero Hourly).
                Set all PRECIPITATION TOTALs (Scaled Hourly)
                to 0.
             ELSE
                DO FOR ALL (BOX (2 km x 2 km Grid))
                   COMPUTE (PRECIPITATION TOTAL (Hourly))
                   COMPUTE (PRECIPITATION TOTAL (Scaled
                           Hourly))
                END DO
          END IF
     1.5  Combine PRECIPITATION TOTALs (Scaled Hourly) with
          IDENTIFIER INFORMATION and appropriate
          SUPPLEMENTAL DATA to produce the 2 km x 2 km
          PRODUCT (Hourly Precipitation).
     1.6  WRITE (PRODUCT (Hourly Precipitation))

     END IF
```

```
2.0  IF (TIME (Three Hour Product Generator) occurred since
        the previous average TIME (Scan) and before or at
        the current average TIME (Scan) AND PRECIPITATION
        TOTALs (Hourly) exist for at least 2 of the last 3
        clock hours)
        THEN
        2.1  DO FOR ALL (BOX (2 km x 2 km Grid))
             2.1.1  COMPUTE (PRECIPITATION TOTAL (Three
                            Hour))
             2.1.2  COMPUTE (PRECIPITATION TOTAL (Scaled
                            Three Hour))
             END DO
        2.2  Combine PRECIPITATION TOTALs (Scaled Three
             Hour) with IDENTIFIER INFORMATION and
             appropriate SUPPLEMENTAL DATA to produce the
             PRODUCT (Three Hour Precipitation).
        2.3  WRITE (PRODUCT (Three Hour Precipitation))
     END IF

3.0  IF (CATEGORY(Precipitation) indicates precipitation has
        occurred during the past 1 hour)
        THEN
        3.1  IF (FLAG (Zero Scan-to-Scan) not set)
                THEN
                   DO FOR ALL (BOX (2 km x 2 km Grid))
                      COMPUTE (PRECIPITATION TOTAL (Storm))
                   END DO
             END IF
        3.2  DO FOR ALL (BOX (2 km x 2 km Grid))
                COMPUTE (PRECIPITATION TOTAL (Scaled Storm))
              END DO
        3.3  Combine PRECIPITATION TOTAL (Scaled Storm) with
             IDENTIFIER INFORMATION and appropriate SUPPLEMENTAL
             DATA to produce the PRODUCT (Storm Total
             Precipitation).
        3.4  WRITE (PRODUCT (Storm Total Precipitation))
        ELSE
        3.5  DO FOR ALL (BOX (2 km x 2 km Grid))
             3.5.1  Set all PRECIPITATION TOTAL (Storm)
                    values to zero.
             END DO
     END IF

END ALGORITHM (PRECIPITATION PRODUCTS)
```

3.2 COMPUTATION

3.2.1 NOTATION

ADP = ARRAY TOTAL (Digital Precipitation), hourly accumulation value for a particular BOX (1/40th LFM Grid), in dBA. A precision of at least 0.5 dBA and dynamic range of at least -18 to 32 dBA is required.

ASHadj = Adjusted ACCUMULATION SCAN (Hourly), adjusted hourly radar precipitation accumulation data for an hourly running period or clock hour on a 1 degree by 2 kilometer polar grid from 1 to 230 km, in dBA. This data has been adjusted for the mean field bias. A precision of at least 0.5 dBA and dynamic range of at least -18 to 32 dBA are required. Includes the beginning TIME (Accumulation) and ending TIME (Accumulation).

PTH = PRECIPITATION TOTAL (Hourly), the hourly precipitation total for a particular BOX (2 km x 2 km Grid), in dBA. A precision of at least 0.5 dBA and dynamic range of at least -18 to 32 dBA are required.

PSH = PRECIPITATION TOTAL (Scaled Hourly), the scaled hourly precipitation total for a particular BOX (2 km x 2 km Grid). Scale codes from 0 to 15 will be used in assigning colors in the final display.

PT3 = PRECIPITATION TOTAL (Three Hour), the three hour precipitation total for a particular BOX (2 km x 2 km Grid), in dBA. A precision of at least 0.5 dBA and dynamic range of at least -18 to 32 dBA are required.

PTS = PRECIPITATION TOTAL (Scaled Three Hour), the scaled three hour precipitation total for a particular BOX (2 km x 2 km Grid). Scale codes from 0 to 15 will be used in assigning colors in the final display.

ASSadj = Adjusted ACCUMULATION SCAN (Scan-to-Scan), total scan-to-scan accumulation data on a 1 degree by 2 km polar grid from 1 to 230 km, in dBA. This data has been adjusted for the estimated mean field bias. A precision of at least 0.5 dBA and dynamic range of at least -29 to 26 dBA are required. Includes the previous average TIME (Scan) and current average TIME (Scan).

SUP = SUPPLEMENTAL DATA, a set of data which will be included as annotations to the four precipitation products.

ID = IDENTIFIER INFORMATION, consists of annotations such as the radar I.D., product name, time (beginning and ending), date and missing period times. The times must be in hours and minutes GMT(Greenwich Mean Time).

APDP = ARRAY PRODUCT (Digital Precipitation), the hourly running total or clock hour total on a 1/40th LFM Grid out to 230 km in a ≥ 100 level computer compatible format, including appropriate supplement data.

PSTcur = Current PRECIPITATION TOTAL (Storm), the current storm precipitation total for a particular BOX (2 km x 2 km Grid), in mm. A precision of at least 0.1 mm and dynamic range of at least 0 to 1600 mm are required.

PSTpre = Previous PRECIPITATION TOTAL (Storm), the precipitation total computed previously, in mm. Precise to 0.1 mm.

PSS = PRECIPITATION TOTAL (Scaled Storm), the scaled precipitation total for a particular BOX (2 km x 2 km Grid). Scale codes 0 to 15 will be used in assigning colors in the final display.

PSTpar = Partial PRECIPITATION TOTAL (Storm), the incremental increase in the precipitation total, in mm. A precision of at least 0.1 mm and dynamic range of at least 0 to 398 mm are required.

AZV = ACCUMULATION (Zero Value), the zero value for scan-to-scan accumulation data, in mm. A precision of at least 0.1 mm and a dynamic range from 0 to 1 mm are required.

AZH = ACCUMULATION (Zero Hourly), the hourly precipitation accumulation considered to be zero, in dBA.

TSavgcur = current average TIME (Scan), the average TIME (Scan) of the current RATE SCAN, to at least 1/1200 hour.

TSavgpre = previous average TIME (Scan), the average TIME (Scan) of the last good rate scan, to at least 1/1200 hour.

PHP = PRODUCT(Hourly Precipitation), the hourly running total or clock hour total on a 2 km x 2 km grid out to 230 kilometers in a 16 level display-compatible format, including appropriate supplemental data.

PSP = PRODUCT(Storm Total Precipitation), depicts the total accumulations since the last one hour break in significant precipitation on a 2 km x 2 km grid out to 230 km in a 16 level display-compatible format, including appropriate supplemental data.

P3H = PRODUCT(Three Hour Precipitation), the three-hour precipitation accumulation over the past three clock hours on a 2 km x 2 km grid out to 230 km in a 16 level display-compatible format, including appropriate supplemental data.

Note: Precision will be units specified unless otherwise stated.

3.2.2 SYMBOLIC FORMULAS

COMPUTE (ARRAY PRODUCT (Digital Precipitation))

$$ADP = 10 \log \left[\frac{\sum_{n=1}^{N} 10^{ASHadj_n/10}}{N} \right]$$

where;

sum is over N adjusted ACCUMULATION SCAN (Hourly) sample volumes specified for a particular BOX (1/40th LFM Grid). Values of N range from 0 to 360 depending on the location, size, and shape of the BOX (1/40th LFM Grid). When N = 0, ADP = 33dBA (a no data flag).

COMPUTE (PRECIPITATION TOTAL (Hourly))

$$PTH = 10 \log \left[\frac{\sum_{n=1}^{N} 10^{ASHadj_n/10}}{N} \right]$$

where;

sum is over all N adjusted ACCUMULATION SCAN (Hourly) sample volumes specified for a particular BOX (2 km x 2 km Grid). Values of N range from 0 to 360 depending on the location of the BOX (2 by 2 km Grid). When N = 0, PTH = AZH.

COMPUTE (PRECIPITATION TOTAL (Scaled Hourly))

PSH (code)	PTH (dBA)
0	$PTH \leq -6$
1	$-6 < PTH \leq 0$
2	$0 < PTH \leq 2$
3	$2 < PTH \leq 4$
4	$4 < PTH \leq 6$
5	$6 < PTH \leq 8$
6	$8 < PTH \leq 10$
7	$10 < PTH \leq 12$
8	$12 < PTH \leq 14$
9	$14 < PTH \leq 16$
10	$16 < PTH \leq 18$
11	$18 < PTH \leq 20$
12	$20 < PTH \leq 22$
13	$22 < PTH \leq 24$
14	$24 < PTH \leq$
15	---

COMPUTE (PRECIPITATION TOTAL (Three Hour))

$$PT3 = 10 \log \left[10^{PTH_n/10} \right]$$

where;

sum is over all n available clock hour PRECIPITATION TOTALs (Hourly) from the last three clock hours with PRECIPITATION TOTAL (Hourly) values greater than ACCUMULATION (Zero Hourly).

COMPUTE (PRECIPITATION TOTAL (Scaled Three Hour))

Same code is used as was used for converting PSH above.

PTS (code) <--- PT3 (dBA)

COMPUTE (PRECIPITATION TOTAL (Storm))

STEP 1

$$PSTpar = \frac{\sum_{n=1}^{N} 10^{ASSadj_n/10}}{N}$$

where, sum is over all N adjusted ACCUMULATION SCAN (Scan-to-Scan) sample volumes specified for a particular BOX (2 km x 2 km Grid). The value of N range from 0 to 360 depending on the location of the BOX (2 by 2 km Grid). When N = 0, PSTpar = 0.

STEP 2

$$PSTcur = \begin{cases} PSTpre + PSTpar \text{ if } PSTpar > AZV \\ PSTpre, \text{ if } PSTpar \leq AZV \end{cases}$$

where,

$$AZV = 10^{AZH/10} \quad (TSavgcur - TSavgpre)$$

Note: AZV is constant for all BOX's (2 km x 2 km Grid).

COMPUTE (PRECIPITATION TOTAL (Scaled Storm))

PSS (code)	PST (mm)
0	PST ≤ 0.3
1	0.3 < PST ≤ 1.5
2	1.5 < PST ≤ 2.5
3	2.5 < PST ≤ 4.0
4	4.0 < PST ≤ 6.5
5	6.5 < PST ≤ 10.0
6	10.0 < PST ≤ 15.0
7	15.0 < PST ≤ 25.0
8	25.0 < PST ≤ 40.0
9	40.0 < PST ≤ 65.0
10	65.0 < PST ≤ 100.0
11	100.0 < PST ≤ 150.0
12	150.0 < PST ≤ 250.0
13	250.0 < PST ≤ 400.0
14	400.0 < PST ≤
15	---

4.0 OUTPUTS

IDENTIFICATION

DATA ARRAY--

- o The ARRAY PRODUCT (Digital Precipitation) providing, in compressed form, the hourly running total or clock hour total on a 131 by 131 1/40th LFM grid is output from this algorithm. The transmission requirements and the efficiency of data compression will be enhanced by transmitting the ARRAY PRODUCT (Digital Precipitation) in dBA units. The appropriate SUPPLEMENTAL DATA are: total number of isolated sample volumes, total number of replaced and interpolated outliers (reflectivity factor), mean percent area reduction and mean bi-scan ratio of all scans during the accumulation period, the number of bad scans during the accumulation period, the area-averaged precipitation rate in each 1/4 LFM grid box for each scan during the accumulation period, the number of interpolated outliers (hourly accumulations), the bias estimate used and its estimation error variance.

- o Selected SUPPLEMENTAL DATA consisting most likely of the PRECIPITATION STATUS MESSAGEs and the compacted 1/4th LFM area-averaged precipitation rate data (8 coded precipitation rate levels) for one or more scans from the past hour. Other SUPPLEMENTAL DATA and IDENTIFIER INFORMATION may also be included.

GRAPHICAL--

- o The PRODUCT (Hourly Precipitation) gives the hourly running total or clock hour total on a 2 km x 2 km grid out to 230 km in a 16 level display compatible format. The appropriate SUPPLEMENTAL DATA are: radar bias estimate, and the error variance of bias estimate.

- o The PRODUCT (Three Hour Precipitation) gives the 3-hour total over the past 3 clock hours on a 2 km x 2 km grid out to 230 km in a 16 level display compatible format. The appropriate SUPPLEMENTAL DATA are: the mean of the three bias estimates used and the maximum of the three error variances.

- o Finally, the PRODUCT (Storm Total Precipitation) depicts the total accumulations since the last one hour break in significant precipitation on a 2 km x 2 km grid out to 230 km in a 16 level display compatible format. The appropriate SUPPLEMENTAL DATA are: the mean of bias estimates used since the storm began and the mean estimation error variance occurring during the storm.

4.2 DISTRIBUTION

Rainfall estimates from this algorithm will be distributed to user sites and used as input to subjective and objective hydrometeorological forecast procedures for flash-flood watches and warnings, river stage monitoring, and water management information applications. Products derived by this algorithm will be distributed as follows:

Data Array Products (ARRAY PRODUCT (Digital Precipitation), Selected SUPPLEMENTAL DATA) - The ARRAY PRODUCT (Digital Precipitation) will be transmitted automatically, once per hour (possibly as often as twice per hour), to the River Forecast Centers (RFC's) and as required to the Weather Service Forecast Office (WSFO's) for input into computer based hydrometeorological models. The selected SUPPLEMENTAL DATA will be transmitted automatically, twice per hour, on the hour and at half past the hour, to the River Forecast Centers (RFC's). Distribution will be directly from the Radar Products Generator (RPG) and from the Principle User External System (PUES) port at the Principle User Processor (PUPS).

Graphical Display Products (PRODUCT (Hourly Precipitation), PRODUCT (Three Hour Precipitation), PRODUCT (Storm Total Precipitation)) - Distributed to WSFO's and RFC's through the PUP.

5.0 INFERENCES

5.1 LIMITATIONS

This algorithm does not provide sufficient intelligence required to distill and integrate heavy precipitation information into a flash flood alert map.

5.2 FUTURE DEVELOPMENTS

The addition of the capability to generate a flash flood alert map will be an important enhancement to consider for the future.

Also, current plans are to develop, based on the SUPPLEMENTAL DATA, IDENTIFIER INFORMATION, and possibly other data processing/quality information, a one or two digit quality status code which would always be displayed with the graphical products. This code would provide the viewer with important information on the processing and quality of the data.

The thresholds for the Graphical Display Products 16 level codes may change in the future. In addition, a dynamic (data-dependent) selection technique for the 16 code thresholds may be developed.

STORM SEGMENTS

ALGORITHM DESCRIPTION

NX-DR-03-022/23

MAJOR REVISIONS SINCE MAY 1984

Storm Segments (022)

1. All algorithms appearing in the May 1984 report have undergone the following changes:

    a. Editorial and typographical changes.

    b. Explicit declaration of data element precision.

    c. Renaming of data element names and symbols to achieve unique naming.

    d. Data Dictionary changes resulting from other changes.

2. Added MASS MULTIPLICATIVE FACTOR, MASS WEIGHTED FACTOR, and PRECIPITATION INTENSITY EXPONENT to the list of adaptable parameters to permit adjustment of weighting factors in the Z-R and M-R relationships.

3. Added REFLECTIVITY AVERAGING FACTOR to the list of adaptable parameters. This permits reporting of the average reflectivity surrounding a point as opposed to the maximum reflectivity at the point.

4. MASS COEFFICIENT FACTOR (MCF) has been changed to PRECIPITATION INTENSITY EXPONENT (PIE).

5. WRITE statements added for MASS WEIGHTED LENGTH and MASS WEIGHTED LENGTH SQUARED.

1.0 PROLOGUE

1.1 FUNCTIONAL DESCRIPTION

This algorithm defines a technique to perform the radial processing step required to identify storms. The procedure identifies radial sequences, or segments, from Doppler radar data. These segments are defined as runs of contiguous sample volumes greater than or equal to a specified reflectivity threshold and having a combined length greater than or equal to a specified length. Also, a specified number of continuous reflectivity values below the reflectivity threshold may be included within each segment, only if these values do not fall below a specified dropout level.

Parameters of each segment are then identified. These parameters include the maximum reflectivity, maximum variance, and the most maximum and most minimum velocity with the associated sample volume. The mass weighted length and mass weighted length squared are also calculated for each segment. These latter two calculations represent the radial portion of the storm mass and position calculations performed in the STORM CENTROIDS [005] algorithm and STORM STRUCTURE [009] algorithm.

1.2 SOURCE

The STORM SEGMENTS algorithm has been implemented by Air Force personnel at the Air Force Geophysics Laboratory (AFGL) in Sudbury, Massachesetts.

REFERENCES

Bjerkaas, C.L., and D.E. Forsyth, 1980: An Automated Real-Time Storm Analysis and Storm Tracking Program (WEATRK). AFGL-TR-80-0316, Air Force Geophysics Laboratory, Hanscom AFB, Massachusetts 01731.

Boak, III, T.I.S., A.J. Jagodnik, Jr., R.B. Marshall, D. Riceman, and M.J. Young, 1977: R & D Equipment Report - Tracking and Significance Estimator. AFGL-TR-77-0259, Air Force Geophysics Laboratory, Hanscom AFB, Massachusetts 01731.

1.3 PROCESSING ENVIRONMENT

This algorithm requires data obtained by direct measurement of reflectivity power and Doppler velocity from a Doppler weather radar. The only preprocessing is the elimination of bad data. This algorithm produces outputs which are inputs to the STORM CENTROIDS [005] algorithm.

2.0 INPUTS

2.1 IDENTIFICATION

AZIMUTH = Azimuthal position, in radians. Precise to 10^{-3} radians.

ELEVATION = Elevation angle, in radians. Precise to 10^{-3} radians.

MASS WEIGHTED FACTOR = A factor used in computing the MASS of a (Sample Volume) (53×10^{9}), in $(hr)(kg)/km^{4}$.

MASS MULTIPLICATIVE FACTOR = A multiplicative factor used in computing the PRECIPITATION INTENSITY (486) in $(mm^{6}/m^{3})\ (hr/mm)^{PIE}$

PRECIPITATION INTENSITY EXPONENT = The power to which the PRECIPITATION INTENSITY is raised in calculating the effective REFLECTIVITY FACTOR (DBZE) (1.37).

RANGE (Slant) = Slant range to the center of a SAMPLE VOLUME, in kilometers.

REFLECTIVITY AVERAGING FACTOR = The number of SAMPLE VOLUMES used for determining the average REFLECTIVITY FACTOR (DBZE)(3).

REFLECTIVITY FACTOR (DBZE) = The effective radar reflectivity factor of a SAMPLE VOLUME in dBZe.

SAMPLE VOLUME = A data sample volume whose dimensions are 1 degree in azimuth, 1 km in range, and 1 degree in depth (perpendicular to the radar beam).

SPECTRUM WIDTH = Spectrum width value, in km/hr.

THRESHOLD (Dropout Number) = The maximum number of SAMPLE VOLUMEs below THRESHOLD (Reflectivity) and above THRESHOLD (Dropout Reflectivity) that may be included in a STORM SEGMENT (2).

THRESHOLD (Dropout Reflectivity) = The minimum effective reflectivity of SAMPLE VOLUMEs that are below THRESHOLD (Reflectivity) that may still be included in a STORM SEGMENT (25), in dBZe.

THRESHOLD (Minimum Reflectivity-2) = The minimum effective reflectivity in a SAMPLE VOLUME to be included in a STORM SEGMENT (30), in dBZe.

THRESHOLD (Segment Length) = The minimum length of a STORM SEGMENT (4.2), in kilometers. Precise to 10^{-4} kilometers.

VELOCITY (Doppler) = Doppler velocities in a data sample volume, in km/hr.

2.2 ACQUISITION

AZIMUTH, ELEVATION and RANGE (Slant) are acquired as measured data from the radar's instantaneous position.

REFLECTIVITY FACTOR (DBZE), SPECTRUM WIDTH and VELOCITY (Doppler) are acquired directly from the Doppler radar hardware.

PRECIPITATION INTENSITY EXPONENT, MASS MULTIPLICATIVE FACTOR, MASS WEIGHTED FACTOR, REFLECTIVITY AVERAGING FACTOR, THRESHOLD (Dropout Number), THRESHOLD (Dropout Reflectivity), THRESHOLD (Segment Length) and THRESHOLD (Minimum Reflectivity-2) are supplied as selected adjustable parameters whose values are based on empirical and theoretical studies of storms. (See Adaptable Parameter Table Appendix C).

SAMPLE VOLUMEs are a direct result of the radar parameters chosen at the time of observation. The sample volume size will be variable depending on range of observation because the radar beam is diverging.

3.0 PROCEDURE

3.1 ALGORITHM

```
BEGIN ALGORITHM (STORM SEGMENTS)

1.0  DO FOR ALL (AZIMUTHs)
     1.1  DO FOR ALL (SAMPLE VOLUMEs)
             IF (REFLECTIVITY FACTOR (DBZE) is greater
                than or equal to THRESHOLD (Reflectivity-2))
                THEN (Begin or continue run of SAMPLE VOLUMEs)
                     Reset NUMBER OF DROPOUTs to zero.
                ELSE
                   IF (REFLECTIVITY FACTOR (DBZE) is
                      greater than THRESHOLD (Dropout Reflec-
                      tivity))
                      THEN
                         Count the NUMBER OF DROPOUTs.
                         IF (NUMBER OF DROPOUTs is greater
                            than THRESHOLD (Dropout Number))
                            THEN
                               End run of SAMPLE VOLUMES.
                            ELSE
                               Continue run of SAMPLE VOLUMES.
                         END IF
                      ELSE
                         End run of SAMPLE VOLUMEs.
                   END IF
                   IF (Dropouts end the run)
                      THEN

                         (End of STORM SEGMENT is last
                         SAMPLE VOLUME above THRESHOLD
                         (Reflectivity-2)).
                   END IF
             END IF

                IF (Run of SAMPLE VOLUMEs is larger than
                   THRESHOLD (Segment Length))
                   THEN
                      Identify run as a STORM SEGMENT.
                END IF
          END DO

     1.2  WRITE (beginning RANGE (Slant))
     1.3  WRITE (ending RANGE (Slant))
     END DO
```

```
2.0  DO FOR ALL (STORM SEGMENTs)
     2.1  COMPUTE (MASS WEIGHTED LENGTH)
     2.2  COMPUTE (MASS WEIGHTED LENGTH SQUARED)
     2.3  DO FOR ALL (SAMPLE VOLUMEs within the STORM
                     SEGMENT)
          2.3.1 COMPUTE (maximum REFLECTIVITY FACTOR
                         (DBZE))
          2.3.2 COMPUTE (maximum SPECTRUM WIDTH)
          2.3.3 COMPUTE (maximum VELOCITY (Doppler))
          2.3.4 COMPUTE (minimum VELOCITY (Doppler))
          END DO
     2.4  WRITE (maximum REFLECTIVITY FACTOR (DBZE))
     2.5  WRITE (maximum SPECTRUM WIDTH)
     2.6  WRITE (maximum VELOCITY (Doppler))
     2.7  WRITE (minimum VELOCITY (Doppler))
     2.8  WRITE (MASS WEIGHTED LENGTH)
     2.9  WRITE (MASS WEIGHTED LENGTH SQUARED)
     END DO

END ALGORITHM (STORM SEGMENTs)
```

3.2 COMPUTATION

3.2.1 NOTATION

SMT = STORM SEGMENT, a set of numbered, contiguous SAMPLE VOLUMEs along a radial identified by reflectivity factor values above a specified threshold. A STORM SEGMENT includes: beginning RANGE(Slant), ending RANGE(Slant), maximum REFLECTIVITY FACTOR (DBZE), most minimum and most maximum VELOCITY (Doppler), maximum SPECTRUM WIDTH, AZIMUTH and ELEVATION angle.

MWL = MASS WEIGHTED LENGTH, mass density weighted length of a STORM SEGMENT, in kg/km^2.

RS = RANGE (Slant), slant range to the center of a SAMPLE VOLUME, in kilometers. Precise to 10^{-4} kilometers.

k = INDEX (Slant Range), the index for RANGE (Slant).

MSV = MASS (Sample Volume), the mass of liquid water content in a SAMPLE VOLUME, in kg/km^3.

PIN = PRECIPITATION INTENSITY, precipitation intensity, in mm/hr (liquid equivalent).

ZE = REFLECTIVITY FACTOR (ZE), the effective radar reflectivity factor of a SAMPLE VOLUME, in mm^6/m^3.

ZU = REFLECTIVITY AVERAGING FACTOR, the number of SAMPLE VOLUMES used for determining the average REFLECTIVITY FACTOR (DBZE) (3).

MWF = MASS WEIGHTED FACTOR, a factor used in computing the MASS of a (Sample Volume) (53×10^9), in (hr) (kg)/km^4.

MMF = MASS MULTIPLICATIVE FACTOR, a multiplicative factor used in computing the PRECIPITATION INTENSITY (486) in (mm^6/m^3) (hr/mm)^{PIE}

DBZE = REFLECTIVITY FACTOR (DBZE), the effective radar reflectivity factor of a SAMPLE VOLUME, in dBZe.

MWS = MASS WEIGHTED LENGTH SQUARED, mass density weighted length squared of a STORM SEGMENT, in kg/km.

DBZEmax = maximum REFLECTIVITY FACTOR (DBZE), the maximum effective radar reflectivity factor, in dBZe.

DBZEavg = average REFLECTIVITY FACTOR (DBZE), the average effective radar reflectivity factor of a group of data SAMPLE VOLUMEs, in dBZe.

Wmax = maximum SPECTRUM WIDTH, the maximum spectrum width value, in km/hr. Precise to .36 km/hr.

W = SPECTRUM WIDTH, spectrum width value, in km/hr. Precise to .36 km/hr.

VDmax = maximum VELOCITY (Doppler), the maximum Doppler velocities, in km/hr. Precise to .36 km/hr.

VDmin = minimum VELOCITY (Doppler), the minimum Doppler velocities, in km/hr. Precise to .36 km/hr.

VD = VELOCITY (Doppler), Doppler velocities in a data SAMPLE VOLUME, in km/hr. Precise to .36 km/hr.

RSbeg = beginning RANGE (Slant), beginning slant range to the center of a SAMPLE VOLUME, in kilometers. Precise to 10^{-4} kilometers.

RSend = ending RANGE (Slant), ending slant range to a center of a SAMPLE VOLUME, in kilometers. Precise to 10^{-4} kilometers.

PIE = PRECIPITATION INTENSITY EXPONENT, the power to which the PRECIPITATION INTENSITY is raised in calculating the effective REFLECTIVITY FACTOR (DBZE)(1.37).

Note: Precision is to units specified unless otherwise stated.

3.2.2 SYMBOLIC FORMULAS

COMPUTE (MASS WEIGHTED LENGTH)

$$MWL = \sum_{k} [(MSV_k)\ (RS_k)]$$

where MSV = (MWF) (PIN)

where PIN is computed from the relation $ZE = (MMF)(PIN)^{PIE}$

and,

$$ZE = 10^{(DBZE/10)}$$

COMPUTE (MASS WEIGHTED LENGTH SQUARED)

$$MWS = \sum_{k} [(MSV_k)\ (RS_k)^2]$$

where MSV is defined earlier.

COMPUTE (maximum REFLECTIVITY FACTOR(DBZE))

$$DBZEavg_k = \left[\sum_{j = k-ZU/2}^{j = k+ZU/2} DBZE_j \right] / ZU$$

$DBZEmax = DBZEavg$ if $DBZEavg_k \geq DBZEmax$

where ZU is the number of SAMPLE VOLUMEs to average.

COMPUTE (maximum SPECTRUM WIDTH)

$Wmax = W_k$ if $W_k \geq Wmax$

COMPUTE (maximum VELOCITY (Doppler))

$VDmax = VD_k$ if $VD_k \geq VDmax$

COMPUTE (minimum VELOCITY (Doppler))

$VDmin = VD_k$ if $VD_k < VDmin$

4.0 OUTPUTS

4.1 IDENTIFICATION

STORM SEGMENTs are sets of contiguous sample volumes containing significant reflectivity. A STORM SEGMENT includes: beginning RANGE (Slant), ending RANGE (Slant), maximum REFLECTIVITY FACTOR (DBZE), most minimum and most maximum VELOCITY (Doppler), maximum SPECTRUM WIDTH, and AZIMUTH and ELEVATION angle.

MASS WEIGHTED LENGTH and MASS WEIGHTED LENGTH SQUARED are sums of length and length squared for each STORM SEGMENT weighted by the mass of each SAMPLE VOLUME.

4.2 DISTRIBUTION

The outputs of this algorithm including REFLECTIVITY FACTOR (DBZE), VELOCITY(Doppler) and SPECTRUM WIDTH are input directly to the STORM CENTROIDS [005] algorithm.

5.0 INFERENCES

5.1 LIMITATIONS

This algorithm only detects segments above a specified length and reflectivity.

TURBULENCE

ALGORITHM DESCRIPTION

NX-DR-01-023/10

MAJOR REVISIONS SINCE MAY 1984

Turbulence (023)

1. All algorithms appearing in the May 1984 report have undergone the following changes:

    a. Editorial and typographical changes.

    b. Explicit declaration of data element precision.

    c. Renaming of data element names and symbols to achieve unique naming.

    d. Data Dictionary changes resulting from other changes.

2. SPECTRUM WIDTH (Normalized Variance) computation was corrected by moving the square inside the parenthesis.

3. The term "heavy turbulence" was changed to "severe turbulence".

1.0 PROLOGUE

1.1 FUNCTIONAL DESCRIPTION

The purpose of this algorithm is to measure the strength of turbulent air motions. This is accomplished through the use of Doppler spectrum variance measurements, along with an estimation of the outer scale of the turbulence for a given meteorological situation, and measurements of radar reflectivity factor.

The contribution of turbulence to the variance of the Doppler spectrum is a function of the size of the data sample volume, the range of the data sample volume from the radar, the turbulence intensity, and the precipitation environment. In the model used in this algorithm the turbulence intensity is related to the rate per unit mass at which kinetic energy is turbulently transferred from larger to smaller scales (the eddy dissipation rate), and the maximum eddy size (turbulence outer scale). Using this information it is possible to estimate the atmospheric turbulence in the vicinity of the radar.

The turbulence algorithm begins by determining whether the site adaptable value for turbulence outer scale is less than 2 km. If so, it then selects the y-intercept, slope and quasi-asymptotic value equations for values less than 2 km. Otherwise it selects the y-intercept, slope and quasi-asymptotic value equations for values greater than or equal to 2 km. The values obtained from the three selected equations are then used by a single equation that estimates the normalized Doppler spectrum variance (normalized to the eddy dissipation rate raised to the 2/3 power times the Kolmogorov constant). This is illustrated in Figure 1.

The final step is to correct the estimated turbulence value for imperfect tracers (precipitation). This correction is based on the fact that small precipitation drops follow turbulent air motions more faithfully than do large drops, therefore producing greater (in magnitude) and more representative turbulence estimates.

1.2 SOURCE

This algorithm has been developed by A. Bohne at the Air Force Geophysics Laboratory (AFGL), Sudbury, Massachusetts.

REFERENCES

Bohne, A. R., 1981: Radar Detection of Turbulence in Thunderstorms, AFGL-TR-81-0102, 62 pp.

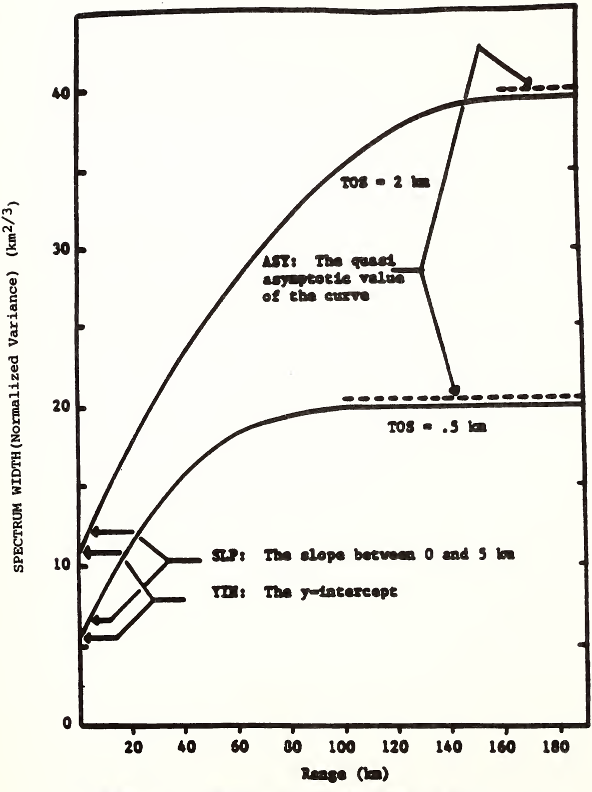

FIGURE 1.0. Doppler Spectrum Variance Normalized to KOL x (eddy dissipation rate)$^{2/3}$ Versus Radar Range for Outer Scale Lengths (TOS) of 0.5 and 2 kilometers.

1.3 PROCESSING ENVIRONMENT

This algorithm requires Doppler reflectivity and spectrum width values, along with a best estimate of the turbulence outer scale.

2.0 INPUTS

2.1 IDENTIFICATION

BEAM WIDTH = The angular width of the radar beam between the half-power points, in radians (.017).

SPECTRUM WIDTH (Variance) = The variance of Doppler spectrum for a data SAMPLE VOLUME, in km^2/hr^2.

KOLMOGOROV CONSTANT = A dimensionless constant used to determine turbulence under local isotropic conditions (1.35).

RANGE (Slant) = Slant range to the center of a SAMPLE VOLUME, in kilometers.

REFLECTIVITY FACTOR (DBZE) = The effective radar reflectivity factor of a SAMPLE VOLUME, in dBZe.

SAMPLE VOLUME = A data sample volume whose dimensions are 1 degree in azimuth, 0.25 km in range, and 1 degree in depth (perpendicular to the radar beam).

TURBULENCE (Outer Scale) = The estimated maximum diameter of turbulent eddies for a particular meteorological event (1-4), in kilometers.

TURBULENCE THRESHOLD (Moderate) = The threshold value indicating the onset of moderate turbulence (6.683888), in $km^{2/3}/hr$.

TURBULENCE THRESHOLD (Severe) = The threshold value indicating onset of severe turbulence (13.367776), in $km^{2/3}/hr$.

2.2 ACQUISITION

BEAM WIDTH is a constant determined by the antenna's characteristic beam width.

SPECTRUM WIDTH (Variance), REFLECTIVITY FACTOR (DBZE) and RANGE (Slant) are acquired directly from the Doppler radar hardware.

KOLMOGOROV CONSTANT is an empirical constant derived from theoretical and scientific studies.

SAMPLE VOLUME is a direct result of the radar parameters chosen at time of observation. The sample volumes will still be variable depending on the range of observation because the radar beam is diverging.

TURBULENCE (Outer Scale) is a site-adaptable parameter whose value is estimated based on the general atmospheric conditions, through theoretical means.

TURBULENCE THRESHOLD (Moderate and Severe) are adaptable parameters and are input by the operator. Values of 6.683888 $km^{2/3}/hr$ (Moderate) and 13.367776 $km^{2/3}/hr$ (Severe) are suggested.

(NOTE: These values are respectively equivalent to 4 $cm^{2/3}/sec$ and 8 $cm^{2/3}/sec$.)

3.0 PROCEDURE

3.1 ALGORITHM

```
BEGIN ALGORITHM (TURBULENCE)

1.0  IF (TURBULENCE (Outer Scale) is less than 2 km)
        THEN
        1.1  COMPUTE (Y-INTERCEPT < 2 KM)
        1.2  COMPUTE (SLOPE < 2 KM)
        1.3  COMPUTE (ASYMPTOTE < 2 KM)
        ELSE
        1.4  COMPUTE (Y-INTERCEPT ≥ 2 KM)
        1.5  COMPUTE (SLOPE ≥ 2 KM)
        1.6  COMPUTE (ASYMPTOTE ≥ 2 KM)
     END IF

2.0  DO FOR ALL (RANGEs (Slant))
     2.1  COMPUTE (SPECTRUM WIDTH (Normalized Variance))
     END DO

3.0  DO FOR ALL (SAMPLE VOLUMEs)
     3.1  COMPUTE (TURBULENCE (Uncorrected))
     3.2  COMPUTE (TURBULENCE)
     3.3  WRITE (TURBULENCE)
     END DO

END ALGORITHM
```

3.2 COMPUTATION

3.2.1 NOTATION

YIN = Y-INTERCEPT, the y-intercept of the curve that estimates SPECTRUM WIDTH (Normalized Variance), in $km^{2/3}$.

TOS = TURBULENCE (Outer Scale), the estimated maximum diameter of turbulent eddies for a particular meteorological event (1-4), in kilometers.

SLP = SLOPE, the slope, between ranges 0 and 5 km, of the curve that estimates the SPECTRUM WIDTH (Normalized Variance), in $km^{2/3}/km$.

ASY = ASYMPTOTE (Quasi), the quasi-asymptotic value, at a range of 220 km, of the curve that estimates the SPECTRUM WIDTH (Normalized Variance), in $km^{2/3}$.

WNV = SPECTRUM WIDTH (Normalized Variance), the normalized SPECTRUM WIDTH (Variance), in $km^{2/3}$.

RS = RANGE (Slant), the slant range to the center of a SAMPLE VOLUME, in km.

k = INDEX (Slant Range), the index for RANGE (Slant).

BW = BEAM WIDTH, the angular width of the radar beam between the half-power points, in radians (.017).

TUU = TURBULENCE (Uncorrected), the turbulence that has not been corrected for precipitation effects, in $km^{4/3}/hr^2$.

WV = SPECTRUM WIDTH (Variance), the variance of Doppler spectrum for a data SAMPLE VOLUME, in km^2/hr^2.

KOL = KOLMOGOROV CONSTANT, a dimensionless constant used to determine turbulence under local isotropic conditions (1.35).

TUR = TURBULENCE, the turbulence that has been corrected for precipitation effects, in $(km^{2/3})/hr$.

DBZE = REFLECTIVITY FACTOR (DBZE), the effective radar reflectivity factor of a SAMPLE VOLUME, in dBZe. Precise to dBZe (Integer value).

PF = PRECIPITATION FACTOR, a dimensionless factor that accounts for imperfect tracers (large drops), when estimating turbulence.

NOTE: Precision is equivalent to 10^{-5} units unless otherwise stated.

3.2.2 SYMBOLIC FORMULAS

COMPUTE (Y-INTERCEPT <2 KM)

$$YIN_{<2} = [7.2467 + 1.110(TOS) - 0.3267(TOS)^2]0.01$$

COMPUTE (SLOPE < 2 KM)

$$SLP_{<2} = [0.2950 + 0.004461(TOS) + 0.02496(TOS)^2]0.01$$

COMPUTE (ASYMPTOTE < 2 KM)

$$ASY_{<2} = [6.6933 + 25.150(TOS) - 2.5933(TOS)^2]0.01$$

COMPUTE (Y-INTERCEPT ≥ 2 KM)

$$YIN_{\geq 2} = [8.083 + 0.0450(TOS) - 0.003333(TOS)^2]0.01$$

COMPUTE (SLOPE ≥ 2 KM)

$$SLP_{\geq 2} = [0.3060 + 0.00475(TOS) - 0.000375(TOS)^2]\ 0.01$$

COMPUTE (ASYMPTOTE ≥ 2 KM)

$$ASY_{\geq 2} = [15.4577 + 16.5125(TOS) - 0.47042(TOS)^2]0.01$$

COMPUTE (SPECTRUM WIDTH (Normalized Variance))

$$WNV_k = \{[YIN + (B_k)\ (SLP)\ (RS)]\ B_k\} + [ASY\ (1 - B_k^2)\ ]$$

where;

$$B_k = e^{[-A(RS)^2]}$$

$$A = [3.559707(BW)^2]/(TOS)^2$$

COMPUTE (TURBULENCE (Uncorrected))

$$TUU_n = (WV_n)/[(KOL)\ (WNV_n)]$$

where;

n is the SAMPLE VOLUME number.

COMPUTE (TURBULENCE)

$TUR_n = [(TUU_n)\ (PF)]^{0.5}$

where;

n is the SAMPLE VOLUME number.

and:

$PF = PMOD - AMOD$

where;

for $RS < 40$ km

$$PMOD = 1.42281 - .0392503(RS) + .0015615(RS)^2 - .0000195982(RS)^3$$

$$AMOD = \{1-[(DBZE + 7)/89]\}\{.305867 - .0314095(RS) + .0014036(RS)^2 - .000019305(RS)^3\}$$

for $RS \geq 40$ km

$PMOD = 1.1$

$AMOD = \{1-[(DBZE + 7)/89]\}(.06)$

4.0 OUTPUTS

4.1 IDENTIFICATION

TUR, the estimated turbulence for each sample volume is output by this algorithm. TUR may be converted to other units (e.g., $cm^{2/3}/sec$) for output.

4.2 DISTRIBUTION

For display, it is suggested that the estimated turbulence values be categorized into three severity categories.

1. Less than moderate for $TUR < TTmod$
2. Equal to or greater than moderate for $TTmod \leq TUR < TTsvr$
3. Equal to or greater than severe for $TUR \geq TTsvr$

The three severity categories may be color coded with higher categories painting over lower categories. Thus, discrimination between hazardous (category 3) and non hazardous (1 and 2) turbulence is possible.

For more information see the Joint-Agency Turbulence Experiment Final Report -- 1984.

5.0 INTERFACES

5.1 LIMITATIONS

The turbulence algorithm is valid for range gate sizes from 200m to 400m.

The values given for TURBULENCE (Outer Scale), TURBULENCE THRESHOLD (Moderate) and TURBULENCE THRESHOLD (Severe) in the list of adaptable parameters are the best estimates available.

The value of 1.35 given for the Kolmogorov Constant is a best estimate.

The turbulence algorithm does not account for wind shear; however, results have shown that wind shear effects may generally be neglected.

Finally, timing and sizing for the present turbulence algorithm could be reduced by transforming the equations for B_k, PMOD, AMOD, YIN, SLP, and ASY into look-up tables.

5.2 FUTURE DEVELOPMENTS

- A more representative estimate of the TURBULENCE (Outer Scale) may result when the algorithm is tested.
- Removal of shear effects.
- A generic set of equations to determine the SPECTRUM WIDTH (Normalized Variance).

DIVERGENCE DETECTION
ALGORITHM DESCRIPTION

NX-DR-03-024/10

MAJOR REVISIONS SINCE MAY 1984

Divergence (024)

1. All algorithms appearing in the May 1984 report have undergone the following changes:

   a. Editorial and typographical changes.

   b. Explicit declaration of data element precision.

   c. Renaming of data element names and symbols to achieve unique naming.

   d. Data Dictionary changes resulting from other changes.

2. COMPUTE (HEIGHT) was corrected by inserting a factor of 2 in the second term.

1.0 PROLOGUE

1.1 FUNCTIONAL DESCRIPTION

The magnitude of divergence at the top of a storm can be associated with the severity of the storm. Strong updrafts in severe storms are directly related to the divergence. Therefore, if the magnitude of divergence is detected, it can be used to identify severe storms.

This algorithm detects and quantifies divergence from radial Doppler velocity data. The algorithm defines a technique that searches for runs of increasing Doppler velocities ("pattern vectors") along each radial. Pattern vectors are obtained by using a seven point, "look-ahead" capability. This procedure, illustrated in Figure 1, compares the next seven radially adjacent velocities by selecting the smallest velocity that is greater than or equal to the current velocity, or "minmax", and labelling it the new "minmax". This procedure is repeated until velocities begin to decrease along the radial. These pattern vectors are then checked against shear and flux thresholds. Runs that pass these thresholds are sorted, according to proximity to each other, and grouped into divergence features.

1.2 SOURCE

The DIVERGENCE DETECTION algorithm has been developed by D. Zrnic' at the National Severe Storms Laboratory (NSSL), Norman, Oklahoma.

REFERENCES

Zrnic', D.S., and Y. Gal-Chen, 1983: Divergence measurement in storm tops.

1.3 PROCESSING ENVIRONMENT

The algorithm requires Doppler radial velocity data which has been dealiased. However, measurement of divergence is sensitive only to the difference of velocities; therefore, improper dealiasing will not affect divergence measurements as long as the error is consistent.

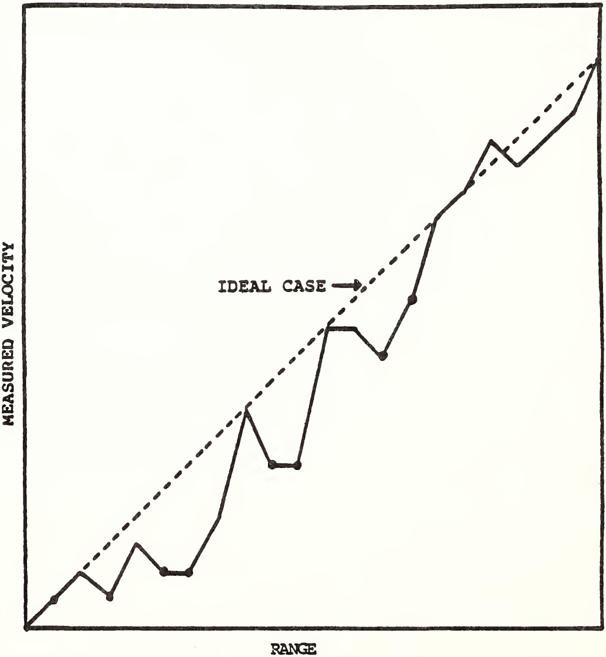

Figure 1: Illustration of the procedure for the construction of pattern vectors. Dots represent "minmax" points which are the boundaries of segments joined into "pattern vectors".

2.0 INPUTS

2.1 IDENTIFICATION

AZIMUTH = Azimuthal position, in radians.

ELEVATION = Elevation angle, in radians.

RANGE (Slant) = The slant range to the center of a SAMPLE VOLUME, in kilometers.

REFLECTIVITY FACTOR (DBZE) = The effective radar reflectivity factor of a SAMPLE VOLUME, in dBZe.

THRESHOLD (Azimuth) = The maximum azimuthal separation between PATTERN VECTORs (0.035), in radians.

THRESHOLD (Divergence Range) = A value that represents the maximum range separation between PATTERN VECTOR centers (3.5), in kilometers.

THRESHOLD (Divergence-High Shear) = A value which represents the minimum magnitude of shear expected in divergence in the presence of minimal air mass flux (7.2), in 1/hr.

THRESHOLD (Divergence-Low Shear) = A value which represents the minimum magnitude of shear expected in divergence (3.6), in 1/hr.

THRESHOLD (High Flux) = A value which represents the minimum magnitude of air mass flux expected in divergence in the presence of minimal shear (108), in 1/hr.

THRESHOLD (Low Flux) = A value which represents the minimum magnitude of air mass flux expected in divergence (36), in 1/hr.

THRESHOLD (Height) = Only pattern vectors above this height threshold will be checked for divergence (8), in kilometers.

VELOCITY (Doppler) = Doppler velocities in a data sample volume, in km/hr.

THRESHOLD (Pattern Vector Number) = The minimum number of PATTERN VECTORs within a feature (6).

THRESHOLD (Velocity Reflectivity) = The REFLECTIVITY FACTOR (DBZE) above which Doppler velocities will be processed (15), in dBZe.

2.2 ACQUISITION

AZIMUTH, ELEVATION and RANGE (Slant) are acquired as measured from the radar's instantaneous position during radial data collection.

REFLECTIVITY FACTOR(DBZE) and VELOCITY (Doppler) are acquired directly from the Doppler radar hardware.

THRESHOLD (Azimuth), THRESHOLD (Divergence Range), THRESHOLD (Divergence-High Shear), THRESHOLD (Divergence-Low Shear), THRESHOLD (High Flux), THRESHOLD (Low Flux), THRESHOLD (Pattern Vector Number), THRESHOLD (Velocity Reflectivity), and THRESHOLD (HEIGHT) are operator supplied adaptable parameters whose values are based on empirical/theoretical studies.

3.0 PROCEDURE

3.1 ALGORITHM

```
BEGIN ALGORITHM (DIVERGENCE DETECTION)

1.0  DO FOR ALL (AZIMUTHs)
     1.1  The first MINMAX is the VELOCITY (Doppler) at the
          first RANGE.
     1.2  DO FOR ALL (RANGEs) WHILE (REFLECTIVITY is greater
          than THRESHOLD (Velocity Reflectivity))
          1.2.1  IF (One of the next seven VELOCITYs
                    (Doppler) is greater than or equal to
                    MINMAX AND is the smallest VELOCITY
                    (Doppler) of the seven AND the end of
                    the radial has not been reached)
                    THEN
                       The VELOCITY (Doppler) is the new
                       MINMAX.
                    ELSE
                       MINMAX is the current VELOCITY
                       (Doppler)
                       COMPUTE (SHEAR (Radial))
                       COMPUTE (FLUX)
                       COMPUTE (HEIGHT (Divergence Feature
                                Center))
                       IF (HEIGHT is greater than THRESHOLD
                          (Height))
                          THEN
                             IF (SHEAR (Radial) is greater
                                than THRESHOLD (Divergence-Low
                                Shear) AND FLUX is greater than
                                THRESHOLD (High Flux)) OR
                                (SHEAR (Radial) is greater
                                than THRESHOLD (Divergence-High
                                Shear) AND FLUX is greater than
                                THRESHOLD (Low Flux))
                                THEN
                                   Store this set of MINMAXes
                                   (including the beginning
                                   and ending ranges) in
                                   PATTERN VECTOR.
                             END IF
                       END IF
                 END IF
          END DO
     END DO

2.0  DO FOR ALL (PATTERN VECTORs) BY (AZIMUTH)
     2.1  IF (AZIMUTH of PATTERN VECTOR is within THRESHOLD
             (Azimuth) of the next PATTERN VECTOR AND the
             RANGE (Slant) between the center of the
             PATTERN VECTORS is within THRESHOLD (Divergence
             Range))
```

```
            THEN
               Include PATTERN VECTORs in the same
               FEATURE.
               Keep count of the number of PATTERN
               VECTORs.
            ELSE
               PATTERN VECTOR is not part of the current
               FEATURE.
         END IF
    END DO

3.0 DO FOR ALL (FEATURES)
    3.1  IF (The number of PATTERN VECTORs is greater than
            or equal to THRESHOLD (Pattern Vector Number))
            THEN
              COMPUTE (maximum VELOCITY (Doppler)
                      difference)
              COMPUTE (average VELOCITY (Doppler)
                      difference)
              COMPUTE (maximum DIVERGENCE (Radial))
              COMPUTE (average DIVERGENCE (Radial))
              COMPUTE (maximum FLUX)
              COMPUTE (average FLUX)
              COMPUTE (FEATURE CENTER POSITION)
              COMPUTE (AREA (Feature))
              COMPUTE (AREA MEASURED (Feature))
              WRITE (maximum VELOCITY (Doppler)
                    difference)
              WRITE (average VELOCITY (Doppler)
                    difference)
              WRITE (maximum DIVERGENCE (Radial))
              WRITE (average DIVERGENCE (Radial))
              WRITE (maximum FLUX)
              WRITE (average FLUX)
              WRITE (FEATURE CENTER POSITION)
              WRITE (AREA (Feature))
              WRITE (AREA MEASURED (Feature))
         END IF
    END DO

END ALGORITHM (DIVERGENCE DETECTION)
```

3.2 COMPUTATION

3.2.1 NOTATION

S = SHEAR (Radial), the change in Doppler velocity along a radial, in 1/hr.

VDbeg = beginning VELOCITY (Doppler), the Doppler velocity at the beginning of a PATTERN VECTOR, in km/hr.

VDend = ending VELOCITY (Doppler), the Doppler velocity at the end of a PATTERN VECTOR, in km/hr.

RSPV = RANGE (Slant Pattern Vector), the slant range of a PATTERN VECTOR, in kilometers. Precise to 10^{-3} km.

RSPVbeg = beginning RANGE (Slant Pattern Vector), the beginning slant range of a PATTERN VECTOR, in kilometers. Precise to 10^{-3} km.

RSPVend = ending RANGE (Slant Pattern Vector), the ending slant range of a PATTERN VECTOR, in kilometers. Precise to 10^{-3} km.

F = FLUX, the air mass flux (per unit mass) associated with divergence, in km^2/hr.

RSavg = average RANGE (Slant), the average slant range of a divergence FEATURE, in kilometers. Precise to 10^{-3} km.

PHI# = ELEVATION, the elevation angle, in radians. Precise to 10^{-3} radians.

RE = RADIUS (Earth), the radius of the Earth (6371), in kilometers. Precise to 10^{-4} km.

VDmaxdif = maximum VELOCITY (Doppler) difference, the maximum Doppler velocity difference in a divergence FEATURE, in km/hr.

VDavgdif = average VELOCITY (Doppler) difference, the average Doppler velocity difference in a divergence FEATURE, in km/hr.

DVRmax = maximum DIVERGENCE (Radial), the maximum radial divergence in a divergence FEATURE, in 1/hr.

DVRavg = average DIVERGENCE (Radial), the average radial divergence in a divergence FEATURE, in 1/hr.

PVE = PATTERN VECTOR, a vector which is formed when a run of increasing Doppler velocity ends. A PATTERN VECTOR contains five components: the slant range, the azimuth angles at both ends of the run, and the Doppler velocities that correspond to those azimuth angles at the slant range.

Fmax = maximum FLUX, the maximum air mass flux (per unit mass) associated with divergence, in km^2/hr.

Favg = average FLUX, the average air mass flux (per unit mass) associated with divergence, in km^2/hr.

FEA = FEATURE, a set of PATTERN VECTORs which have passed spacial proximity thresholds.

FCP = FEATURE CENTER POSITION, the FEATURE center position in range, elevation and azimuth.

AF = AREA (Feature), the estimated area of the divergence FEATURE, in km^2.

AMF = AREA MEASURED (Feature), the measured area of the divergence FEATURE (the summation of PATTERN VECTOR areas), in km^2.

HDFC = HEIGHT (Divergence Feature Center), the height of the divergence FEATURE center, in km. Precise to 10^{-3} km.

Note: Precision will be units specified unless otherwise stated.

3.2.2 SYMBOLIC FORMULAS

COMPUTE (SHEAR (Radial))

$$S = (VDend - VDbeg) / (RSPVend - RSPVbeg)$$

COMPUTE (FLUX)

$$F = (VDend - VDbeg)\ (RSPVend - RSPVbeg)$$

COMPUTE (HEIGHT (Divergence Feature Center))

$$HDCF = [(RSavg) \sin \phi] + [(RSavg \cos \phi)^2 / (8/3\ RE)]$$

where;

$$RSavg = \{ \sum_n [(RSPVend + RSPVbeg)/2]_n \} /n$$

and n is the number of SAMPLE VOLUMEs within a potential PATTERN VECTOR.

COMPUTE (maximum VELOCITY (Doppler) difference)

$$\text{VDmaxdif} = \text{maximum } (\text{VDend} - \text{VDbeg})$$

COMPUTE (average VELOCITY (Doppler) difference)

$$\text{VDavgdif} = [\sum_{n} (\text{VDend} - \text{VDbeg})] / n$$

where n is the number of PATTERN VECTORs within a particular divergence FEATURE.

COMPUTE (maximum DIVERGENCE (Radial))

$$\text{DVRmax} = \text{maximum } [(\text{VDend} - \text{VDbeg}) / (\text{RSPVend} - \text{RSPVbeg})]$$

COMPUTE (average DIVERGENCE (Radial))

$$\text{DVRavg} = [\sum_{n} (\text{VDend} - \text{VDbeg}) / (\text{RSPVend} - \text{RSPVbeg})] / n$$

where n is the number of PATTERN VECTORs within a particular divergence FEATURE.

COMPUTE (maximum FLUX)

$$\text{Fmax} = \text{maximum } [(\text{VDend} - \text{VDbeg}) (\text{RSPVend} - \text{RSPVbeg})]$$

COMPUTE (average FLUX)

$$\text{Favg} = [\sum_{n} (\text{VDend} - \text{VDbeg}) (\text{RSPVend} - \text{RSPVbeg})] / n$$

where n is the number of PATTERN VECTORs within a particular divergence FEATURE.

COMPUTE (FEATURE CENTER POSITION)

FCP = (AZavg, RSavg) where;

$\text{AZavg} = [\sum_{n} \text{AZ}_n] / n$ and RSavg is defined above.

where n is the number of PATTERN VECTORs within a particular divergence FEATURE.

COMPUTE (AREA (Feature))

$$\text{AF} = (\text{RSavg}) (\text{AZend} - \text{AZbeg}) (\text{RSPVend} - \text{RSPVbeg})$$

COMPUTE (AREA MEASURED (Feature))

$$\text{AMF} = \sum_{n} \{[(\text{RSPVend} + \text{RSPVbeg})/2] (\text{RSPVend} - \text{RSPVbeg})$$

$$(\pi/180)\}_n$$

where n is the number of PATTERN VECTORs within a particular divergence FEATURE.

4.0 OUTPUTS

4.1 IDENTIFICATION

The outputs of this algorithm describe characteristics of divergence that are used to determine the severity of storms. The outputs are: maximum VELOCITY (Doppler) difference, average VELOCITY (Doppler) difference, maximum DIVERGENCE (Radial), average DIVERGENCE (Radial), maximum FLUX, average FLUX, FEATURE CENTER POSITION, AREA (Feature), and AREA MEASURED (Feature) per divergence FEATURE.

4.2 DISTRIBUTION

The outputs of this algorithm could be used in severe weather warning procedures.

5.0 INFERENCES

5.1 LIMITATIONS

No major limitations are noted at this time.

5.2 FUTURE DEVELOPMENTS

Much work remains to be done before the algorithm can be put into operational use. Some comparisons with measurements made from two Doppler radars should establish aspect sensitivity of the method. Also classification criteria for separating severe, potentially severe, and nonsevere storms must be established. This can only be done if the algorithm is applied to several cases of known severity and the outputs are examined.

TVS DETECTION

ALGORITHM DESCRIPTION

NX-DR-01-026/10

MAJOR REVISIONS SINCE MAY 1984

TVS Detection (026)

1. All algorithms appearing in the May 1984 report have undergone the following changes:

   a. Editorial and typographical changes.

   b. Explicit declaration of data element precision.

   c. Renaming of data element names and symbols to achieve unique naming.

   d. Data Dictionary changes resulting from other changes.

2. Noted need for COMPUTE (ORIENTATION) to handle the case where Q1=0 thus preventing division by zero.

3. Divided formulas with PCT by 100 because PCT is percent.

4. Changed documentation to acknowledge the FEATURE EXTREMA (viz., RSFEbeg, RSFEend, AZbegfe and AZendfe) input from the Mesocyclone Detection Algorithm.

5. WRITE commands for maximum VELOCITY (Doppler), minimum VELOCITY (Doppler), POSITION (Maximum Velocity) and POSITION (Minimum Velocity) located immediately before the END DO at the bottom of section 1.1.2 were moved to occur immediately after that END DO.

6. Corrected the compute for maximum SHEAR (TVS).

7. Added WRITE Mesocyclone ID immediately after section 1.0 DO FOR ALL (Mesocyclones). This will support the TVS product.

8. RADIUS CORRECTION (Earth) has been deleted from the list of adaptable parameters.

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8. RADIUS CORRECTION (Earth) has been deleted from the list of adaptable parameters.

1.0 PROLOGUE

1.1 FUNCTIONAL DESCRIPTION

The function of this algorithm is to describe a process that detects tornado vortex signatures (TVS) near mesocyclones.

The most maximum and most minimum Doppler velocities at the same elevation near mesocyclones are compared to determine if a tornado vortex signature exists. A mesocyclone is defined as a three-dimensional region in a storm which rotates (usually cyclonically), and is closely correlated with severe weather. Parameters computed include the shear, distance between most maximum and most minimum and orientation. These values are compared to thresholds and if they are exceeded, a potential TVS is identified. This process is repeated for every elevation near the mesocyclone. If potential TVS's are identified at two or more elevations near a mesocyclone then a TVS is shown detected within that particular storm occurring at the present time.

The TVS DETECTION algorithm described has been implemented Air Force personnel at the Air Force Geophysics Laboratory (AFGL) in Sudbury, Massachusetts.

1.3 PROCESSING ENVIRONMENT

Input data used by the TVS DETECTION algorithm must be preprocessed for velocity unfolding and elimination of ground clutter.

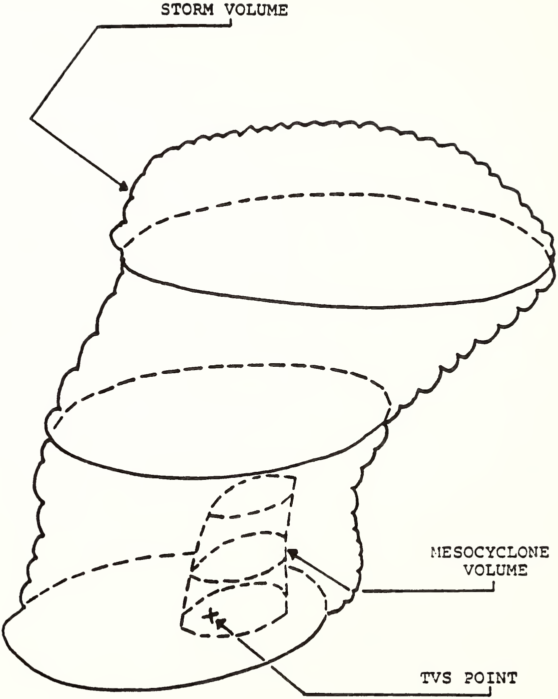


Figure 1. Spatial relationship between a TVS and a mesocyclone within a storm.

2.0 INPUTS

2.1 IDENTIFICATION

AZIMUTH = Azimuthal position, in radians. Precise to 10^{-3} radians.

ELEVATION = Elevation angle, in radians.

RANGE (Slant) = The slant range to the center of a SAMPLE VOLUME, in kilometers. Precise 10^{-4} kilometers.

FEATURE = A set of PATTERN VECTORs which have passed spatial proximity.

MESOCYCLONE ID = ID assigned to a mesocyclone when the MESOCYCLONE Algorithm identifies a mesocyclone.

FEATURE EXTREMA = A set of four parameters (beginning RANGE(Slant-Feature), ending RANGE (Slant-Feature), beginning feature AZIMUTH and ending Feature AZIMUTH). These are the maximum and minimum AZIMUTHS of its PATTERN VECTOR LIST, and the maximum and minimum ranges from the PATTERN VECTOR LIST.

SEARCH PERCENTAGE = The percent areal increase for searching for TVSs (.05), unitless. (.05) is equivalent to 5 percent).

THRESHOLD (TVS Shear) = The minimum SHEAR (TVS) expected within a TVS FEATURE (180), in 1/hour.

VELOCITY (Doppler) = Doppler velocities in a data sample volume, in km/hr.

RADIUS CORRECTION (Earth) = The factor by which the RADIUS(Earth) is multiplied to account for refraction of the radar beam (1.21).

2.2 ACQUISITION

AZIMUTH and ELEVATION are obtained by direct measurement of the radar pointing direction.

RANGE (Slant) and VELOCITY (Doppler) are acquired by direct radar measurement.

SEARCH PERCENTAGE, RADIUS CORRECTION(Earth), and THRESHOLD (TVS Shear) are system supplied thresholds based on scientific/ theoretical studies.

MESOCYCLONE ID, FEATURE, and FEATURE EXTREMA are obtained from the MESOCYCLONE DETECTION [002] algorithm.

3.0 PROCEDURE

3.1 ALGORITHM

```
BEGIN ALGORITHM (TVS DETECTION)

1.0  DO FOR ALL (MESOCYCLONE ID's)
     WRITE  MESOCYCLONE ID
     1.1  DO FOR ALL (ELEVATIONs within the mesocyclone)
          1.1.1  COMPUTE (SEARCH BOUNDARY)
          1.1.2  DO FOR ALL (AZIMUTHs at or within SEARCH
                            BOUNDARY)
                    DO FOR ALL (RANGEs at or within SEARCH
                               BOUNDARY)
                       COMPUTE (maximum VELOCITY (Doppler
                               Range))
                       COMPUTE (minimum VELOCITY (Doppler
                               Range))
                       COMPUTE (RANGE (Maximum))
                       COMPUTE (RANGE (Minimum))
                    END DO
                    COMPUTE (maximum VELOCITY (Doppler))
                    COMPUTE (minimum VELOCITY (Doppler))
                    COMPUTE (POSITION (Maximum Velocity))
                    COMPUTE (POSITION (Minimum Velocity))
                 END DO
                 WRITE (maximum VELOCITY (Doppler))
                 WRITE (minimum VELOCITY (Doppler))
                 WRITE (POSITION (Maximum Velocity))
                 WRITE (POSITION (Minimum Velocity))
          1.1.3  COMPUTE (SHEAR (TVS))
          1.1.4  COMPUTE (ORIENTATION)
          1.1.5  COMPUTE (ROTATION)
          1.1.6  IF (SHEAR (TVS) is greater than THRESHOLD
                    (TVS Shear) AND ROTATION is cyclonic AND
                    ORIENTATION is less than or equal to
                    .785 radians)
                    THEN
                       Identify as a potential TVS Feature.
                       WRITE (ORIENTATION)
                       WRITE (SHEAR (TVS))
                       WRITE (ROTATION)
                       COMPUTE (SHEAR POSITION)
                       WRITE (SHEAR POSITION)
                 END IF
          END DO
```

```
    1.2  IF (potential TVS FEATUREs are identified at two
            or more elevations)
            THEN
               Identify a TVS FEATURE.
               COMPUTE (maximum SHEAR (TVS))
               COMPUTE (TVS FEATURE POSITION)
               WRITE (TVS FEATURE POSITION)
               WRITE (maximum (SHEAR (TVS))
         END IF
    END DO

END ALGORITHM
```

3.2 COMPUTATION

3.2.1 NOTATION

SB = SEARCH BOUNDARY, the boundary (including SEARCH PERCENTAGE) of the area enclosing a FEATURE, in range and azimuth.

SBRbeg = beginning SEARCH BOUNDARY (Slant Range), the beginning slant range of a FEATURE adjusted for the SEARCH PERCENTAGE, in kilometers. Precise to 10^{-4} kilometers.

RSFEbeg = beginning RANGE (Slant-Feature), the beginning slant range of a FEATURE, in kilometers. Precise to 10^{-4} kilometers.

SBRend = ending SEARCH BOUNDARY (Slant Range), the ending slant range of a FEATURE adjusted for SEARCH PERCENTAGE, in kilometers. Precise to 10^{-4} kilometers.

RSFEend = ending RANGE (Slant-Feature), the ending slant range of a FEATURE, in kilometers. Precise to 10^{-4} kilometers.

PCT = SEARCH PERCENTAGE, the percent areal increase for searching for TVSs (.05), unitless. (.05 is equivalent to 5 percent).

SBAbeg = beginning SEARCH BOUNDARY (Azimuth), the beginning azimuth of a FEATURE adjusted for the SEARCH PERCENTAGE, in radians. Precise to 10^{-3} radians.

AZbegfe = beginning feature AZIMUTH, the beginning azimuth of a FEATURE, in radians. Precise to 10^{-3} radians.

AZendfe = ending feature AZIMUTH, the ending azimuth of a FEATURE, in radians. Precise to 10^{-3} radians.

SBAend = ending SEARCH BOUNDARY (Azimuth), the ending azimuth of a FEATURE adjusted for the SEARCH PERCENTAGE, in radians. Precise to 10^{-3} radians.

VDRmax = maximum VELOCITY (Doppler Range), the maximum Doppler velocity along each radial, in km/hr. Precise to .36 km/hr.

RSM = RANGE (Maximum), the slant range of maximum VELOCITY (Doppler Range), in kilometers. Precise to 10^{-4} kilometers.

k = INDEX (Slant Range), the index for RANGE (Slant).

VD = VELOCITY (Doppler), the Doppler velocities in a data sample volume, in km/hr. Precise to .36 km/hr.

VDRmin = minimum VELOCITY (Doppler Range), the minimum Doppler velocity along each radial, in km/hr. Precise to .36 km/hr.

RSN = RANGE (Minimum), the slant range of minimum VELOCITY (Doppler Range), in kilometers. Precise to 10^{-4} kilometers.

RMV = RANGE (Maximum Velocity), the slant range of maximum VELOCITY (Doppler Range) within a FEATURE, in kilometers. Precise to 10^{-4} kilometers.

RNV = RANGE (Minimum Velocity), the slant range of minimum VELOCITY (Doppler Range) within a FEATURE, in kilometers. Precise to 10^{-4} kilometers.

VDmax = maximum VELOCITY (Doppler), the maximum Doppler velocities, in km/hr. Precise to .36 km/hr.

VDmin = minimum VELOCITY (Doppler), the minimum Doppler velocities, in km/hr. Precise to .36 km/hr.

AMV = AZIMUTH (Maximum Velocity), the azimuth of a maximum VELOCITY (Doppler Range) within a FEATURE, in radians. Precise to 10^{-3} radians.

ANV = AZIMUTH (Minimum Velocity), the azimuth of a minimum VELOCITY (Doppler Range) within a FEATURE, in radians. Precise to 10^{-3} radians.

STV = SHEAR (TVS), the change between the maximum and minimum Doppler velocities within a FEATURE at the same elevation, in 1/hr. Precise to 1/3600 hr.

ORI = ORIENTATION, the orientation of the maximum and minimum Doppler velocity locations within a FEATURE at the same elevation, in radians. Precise to 10^{-3} radians.

ROT = ROTATION, the rotation of the velocity field within a FEATURE at the same elevation, in radians. Precise to 10^{-3} radians.

SHP = SHEAR POSITION, the position in range and azimuth of the maximum SHEAR (TVS) position.

SRR = SHEAR POSITION (Range), the slant range of the SHEAR POSITION, in kilometers. Precise to 10^{-4} kilometers.

SRA = SHEAR POSITION (Azimuth), the azimuth of the SHEAR POSITION, in radians. Precise to 10^{-3} radians.

STVmax = maximum SHEAR (TVS), the maximum change between the maximum and minimum Doppler velocities within a FEATURE at the same elevation in 1/hr. Precise to 1/3600/hr.

TVS = TVS FEATURE POSITION, the position of a TVS FEATURE in range, azimuth and height.

HTVS = HEIGHT (TVS Feature), the height above the ground of a TVS FEATURE, in kilometers. Precise to 10^{-4} kilometers.

PHI# = ELEVATION, the elevation angle, in radians. Precise to 10^{-3} radians.

RCOE = RADIUS CORRECTION (Earth), the factor by which the RADIUS (Earth) is multiplied to account for refraction of the radar beam (1.21).

RE = RADIUS (Earth), the radius of the Earth (6371), in kilometers. Precise to 10^{-4} kilometers.

AZfe = feature AZIMUTH, the azimuthal positions of a FEATURE, in radians. Precise to 10^{-3} radians.

RSFE = RANGE(Slant-Feature), the slant ranges of a FEATURE, in kilometers. Precise to 10^{-4} kilometers.

3.2.2 SYMBOLIC FORMULAS

COMPUTE (SEARCH BOUNDARY)

SB = (RS,AZ)

SBRbeg = RSFEbeg - (PCT)(RSFEend - RSFEbeg)

If SBRbeg is less than zero, then SBRbeg = zero.

SBRend = RSFEend + (PCT)(RSFEend - RSFEbeg)

If SBRend is greater than the maximum range, then SBRend = the maximum range.

SBAbeg = AZbegfe - [(PCT)(|AZbegfe - AZendfe|)]

SBAend = AZendfe + [(PCT)(|AZbegfe - AZendfe|)]

Note: Correct for crossing zero radians.

COMPUTE (maximum VELOCITY (Doppler Range))

VDRmax = VD_k if $VD_k \geq$ VDRmax

COMPUTE (minimum VELOCITY (Doppler Range))

VDRmin = VD_k if $VD_k <$ VDRmin

COMPUTE (RANGE (Maximum))

RSM = RANGE (Slant) of VDRmax

COMPUTE (RANGE (Minimum))

RSN = RANGE (Slant) of VDRmin

COMPUTE (maximum VELOCITY (Doppler))

$VDmax = VDRmax_k$ if $VDRmax_k > VDmax$

COMPUTE (minimum VELOCITY (Doppler))

$VDmin = VDRmin_k$ if $VDRmin_k < VDmin$

COMPUTE (POSITION (Maximum Velocity))

AMV = AZIMUTH of VDmax, RMV = RANGE of VDmax

COMPUTE (POSITION (Minimum Velocity))

ANV = AZIMUTH of VDmin, RNV = RANGE of VDmin

COMPUTE (SHEAR (TVS))

$STV = (VDmax - VDmin)/[(RMV - RNV)^2 + (Q1)^2]^{0.5}$

where $Q1 = [(RMV + RNV)\{\sin[(AMV - ANV)/2.0]\}]$

Note: Must correct for crossing zero radians.

Note: Case for Q1 = 0 must be handled to avoid division by zero in COMPUTE (ORIENTATION)

COMPUTE (ORIENTATION)

$ORI = \tan^{-1}[|(RMV - RNV)/Q1|]$

where Q1 is defined above.

COMPUTE (ROTATION)

$ROT = AMV - ANV$

where positive is cyclonic.

Note: Must correct for crossing zero radians.

COMPUTE (SHEAR POSITION)

SHP = (SRR, SRA)

SRR = (RMV + RNV)/2.0

SRA = (AMV + ANV)/2.0

Note: Must correct for crossing zero radians.

COMPUTE (maximum SHEAR (TVS))

STVmax = STV if STV $\geq$ STVmax

COMPUTE (TVS FEATURE POSITION)

TVS = (RS,AZ,HTVS)

RS = SRR if SRR is the position of STVmax

AZ = SRA if SRA is the position of STVmax

$$\mathrm{HTVS} = \{[(\mathrm{RMV} + \mathrm{RNV})/2](\sin\phi)\} + \{[(\mathrm{RMV} + \mathrm{RNV})/2]^2/[(2)(\mathrm{RCOE})(\mathrm{RE})]\}$$

4.0 OUTPUTS

IDENTIFICATION

TVS feature positions and their associated shear (with ORIENTATION) and ROTATION values will be output by this algorithm.

In addition, the following are also outputs:

- MESOCYCLONE ID
- position and value of maximum velocities for each feature
- shear, orientation, rotation, and shear position for each feature identified as a potential TVS
- position and maximum shear of the TVS (defined to exist when 2 or more potential TVS's are identified)

4.2 DISTRIBUTION

Output from the TVS DETECTION algorithm may be input to a TVS tracking of forecasting routine. The output may also be used for severe weather warning procedures.

5.0 INFERENCES

5.1 LIMITATIONS

The TVS Detection Algorithm is based on the relative positions of the maximum inbound and outbound velocities. These velocities are point values that are susceptible to errors due to velocity aliasing, range aliasing, noise, clutter, and thresholding.

5.2 FUTURE DEVELOPMENTS

There are currently no plans for future improvements. Development of an algorithm similar to the MESOCYCLONE Algorithm with TVS thresholds should be investigated.

SECTORIZED UNIFORM WIND
ALGORITHM DESCRIPTION

NX-DR-03-027/04

1.0 PROLOGUE

1.1 FUNCTIONAL DESCRIPTION

The sectorized uniform wind algorithm evaluates the azimuthal derivative of the radial component of the wind at constant range to estimate the transverse component. A centered finite difference approximation (to the derivative) provides an unbiased estimate of the transverse component of the wind if it is uniform over the arc length on which the derivative is estimated and this arc length is small (< 5^{o}).

Because transverse wind estimates have variance which is inversely proportional to the arc length, filtering of radial velocities is needed prior to evaluating the derivative. Filtering over at least 30^{o} in azimuth is needed to reduce the variance to acceptable levels (approximately 1 m^{2} s^{-2}). (See, for example, Doviak and Zrnic, 1984, p. 266, or Lawrence, et.al., (1975).

The algorithm could, in principle be applied to every range gate with independent estimates made every 30^{o} in azimuth. However, because of the smoothing required in the azimuthal direction, some smoothing can be done in range to reduce the number of computations without adversely affecting the resolution. Interpretation of the results is facilitated if estimates are made more often in azimuth than the 30^{o} required for independence. Experience with the algorithm in frontal situations indicates that estimates spaced 10^{o}in azimuth and about 7 kilometers in range are acceptable.

The radial velocities are edited and averaged in range so the averages are spaced about 7 kilometers. The averaged radial velocities are low pass filtered in the azimuthal direction. The radial and transverse components are computed from the filtered averaged values. Wind speed and direction are then computed from these radial and transverse components.

1.2 SOURCE

The uniform wind algorithm was studied by Lawrence et al. (1975) and Easterbrook (1975). Further work is discussed by Clifford (1980); an application to radar data is discussed by Rabin and Doviak (1982). The algorithm has been implemented at National Severe Storms Laboratory (NSSL) on a Perkin Elmer 3242 by Al Koscielny.

REFERENCES

Clifford, S.F., T.R. Lawrence, G.R. Ochs, and T-i Wang, 1980: "Study of a Pulsed Coherent Lidar for Crosswind Sensing", NOAA Tech Memo ERL WPL-48. Available Natl. Tech. Inf. Serv., Operations Div., Springfield, Virginia.

Duchon, C.E., 1979: Lanczos filtering in one and two dimensions. J. Appl. Meteor., 18, 1016-1022.
Easterbrook, C.C., 1975: Estimating horizontal wind fields by two-dimensional curve fitting of single doppler radar measurements. Preprints, Radar Meteorology Conf., 16th, 1975, 214-219.

Lawrence, T.R., M.C. Krause, C.E. Craven, L.K. Morrison, J.A.L. Thomson, W.C. Cliff, and R.M. Huffaker, 1975: "A Laser Doppler System for the Remote Sensing of Boundary Layer Winds in Clear Air Conditions". Preprints, Radar Meteorology Conf., 16th, 1975, 320-327.

Rabin, R.M., and R.J. Doviak, 1982: Prestorm observations in the clear air boundary layer with a Doppler radar. Preprints, Severe Local Storms Conf., 12th, 1982, 425-429

1.3 PROCESSING ENVIRONMENT

The algorithm requires radial velocity estimates to have error variances no larger than 2 m/s. It is necessary to correct velocity aliasing and range folding. In addition, ground clutter, point targets, and noise should be edited. In statiform precipitation, signal to noise ratio (SNR) thresholding followed by modal editing should be adequate. For clear air signals, SNR's may not be measured with enough resolution by the returned power. With these low SNR's, the spectrum width (biased by noise) provides a better measure of SNR and thresholding should be done based on SNR and maximum spectrum width.

2.0 INPUTS

2.1 IDENTIFICATION

AZIMUTHS (Filtered Velocities) = A set of AZIMUTHS for which VELOCITY FILTERED will be calculated. This is currently specifed as groups of 3 adjacent AZIMUTHS centered every 10° around an AZIMUTH sweep, beginning at 0°, in radians. Precise to 1.75 x 10^{-3} radians.

AZIMUTH = Azimuthal position, in radians. Precise to 1.75 x 10^{-3} radians.

DATA(Bad) = A value which indicates missing or poor quality data assigned to velocity data to prevent processing by the algorithm.

ELEVATION = Elevation angle, in radians. Precise 1.75 x 10^{-3} radians.

GAP (Maximum) = The maximum number of radians over which a gap can exist in velocity data around an AZIMUTH sweep at one range and still have linear interpolation performed across it to estimate the missing velocity values. Precise to 1.75 x 10^{-3} radians.

FREQUENCY (Cutoff) = The cutoff frequency of the filter (.015 cycles per data interval recommended by the author).

INTERVAL (Average) = An interval, in kilometers, over which velocity data are to be averaged over a radial, i.e., the length of a RANGE INTERVAL (6.75 is currently used in NSSL implementation). Precise to 10^{-4} km.

INTERVAL (Class) = One of a set of intervals into which VELOCITYs(Doppler) are divided in order to determine first, the modal (or most frequent value), and then the average value of the VELOCITY(Doppler) over a RANGE INTERVAL. Each INTERVAL (Class) has a width of INTERVAL (Width).

INTERVAL (Width) = The width of a class interval for determining an average velocity in a RANGE INTERVAL (7.2 km/hr is currently used in NSSL implementation).

NUMBER (Weights) = The number of unique Lanczos filter weights used to obtain the desired filtering characteristics. It must be an odd number with 51 currently being used in the NSSL implementation.

RANGE INTERVAL = The interval over which to average the velocities over a radial before the wind field is computed, in kilometers (6.75 is currently used in NSSL implementation.) Precise to 10^{-4} km.

RANGE (Slant) = The slant range to the center of a SAMPLE VOLUME, in kilometers. Precise to 10^{-4}kilometers.

VELOCITY (Doppler) = Doppler velocities in a data SAMPLE VOLUME, in km/hr. Precise to .1 m/s.

VELOCITY (Minimum Number) = The minimum number of velocities which must be in the INTERVAL(MODE) before an average velocity is computed.

2.2 ACQUISITION

AZIMUTH, ELEVATION, RANGE(Slant) and VELOCITY (Doppler) are acquired directly from the radar.

VELOCITY(Minimum Number), INTERVAL(Average), INTERVAL(Class), INTERVAL(Width), AZIMUTH(Filtered Velocities), RANGE INTERVAL, GAP(Maximum) and DATA(Bad) are empirically determined parameters that may vary depending on the application and are also site-adaptable. The Lanczos filter weights FREQUENCY(Cutoff) and (Number(Weights)) are theoretically determined (Duchon, 1979).

3.0 PROCEDURE

3.1 ALGORITHM

```
BEGIN ALGORITHM (SECTORIZED UNIFORM WIND)

1.0  COMPUTE (NUMBER)
     1.1  DO FOR ALL (Lanczos Filter weights from 0 to N)
          1.1.1  COMPUTE (WEIGHT(Lanczos Filter))
          END DO
     1.2  DO FOR ALL (Lanczos Filter weights from 0 to N)
          1.2.1  COMPUTE (WEIGHT (Sum))
          END DO
     1.3  DO FOR ALL (Lanczos filter weights from 0 to N)
          1.3.1  COMPUTE (WEIGHT(Normalized))
          END DO

2.0 DO FOR ALL (ELEVATIONS which have enough good quality data)
      2.1  DO FOR ALL (Radials in one AZIMUTH sweep) BY (RANGE
                       INTERVAL)
           2.1.1  DO FOR ALL (VELOCITYs (Doppler) not equal to
                             DATA (Bad) in each RANGE INTERVAL)
                  DO FOR ALL (INTERVAL (Class) of width INTER-
                             VAL (Width))
                      COMPUTE  (VELOCITY(Number in Interval)
                      COMPUTE  (VELOCITY(Interval Center))
           2.1.2  IF (INTERVAL (Mode) contains VELOCITY (Minimum
                     Number) or more values)
                      THEN COMPUTE (VELOCITY (Range Interval
                                    Averaged))
                      ELSE  (Set VELOCITY (Range Interval Aver-
                            aged) equal to DATA (Bad))
                  END IF
                  END DO
                  END DO
      2.2  IF (Any VELOCITYs (Range Interval Averaged)
              are equal to DATA (Bad)
           THEN COMPUTE (GAP)
              THEN
                    IF (GAP is less than or equal to GAP
                       (Maximum))
                    THEN
                        DO FOR ALL (Missing VELOCITYs
                                   (Doppler) in the gap)
                        COMPUTE (VELOCITY (Interpolated))
                        END DO
                    END IF
           END IF
```

```
        2.3  DO FOR ALL (AZIMUTHs (Filtered Velocities)) BY (RANGE
                       INTERVAL)
                 COMPUTE (VELOCITY FILTERED at AZIMUTH (Filtered
                         Velocity))
                   IF (VELOCITY FILTERED(Before) AND VELOCITY
                      (Azimuthal Derivative) AND VELOCITY FILTERED
                      (After) are not equal to DATA(Bad))
                  THEN COMPUTE (DERIVATIVE (Azimuthal))
                       COMPUTE (WIND SPEED)
                       COMPUTE (WIND(Direction))
                       COMPUTE (WIND (Meteorological Direction))
                  ELSE (Set WIND SPEED and WIND(Meteorological
                        Direction equal to DATA (Bad))
                   END IF
                   WRITE  (WIND SPEED)
                   WRITE  (WIND(Meteorological Direction))
              END DO
              END DO
     END DO
END ALGORITHM  (SECTORIZED UNIFORM WIND)
```

3.2 COMPUTATION

3.2.1 NOTATION

AFLaft = After AZIMUTH (Filtered Velocity), the AZIMUTH of the radial after AZIMUTH (Filtered Velocity), in radians.

AFLbef = Before AZIMUTH (Filtered Velocity), the AZIMUTH of the radial before AZIMUTH (Filtered Velocity), in radians.

AZbegi = Begin interpolation AZIMUTH, the AZIMUTH at which VELOCITY (Begin Interpolation) is located, in radians.

AZendi = End interpolation AZIMUTH, the AZIMUTH at which VELOCITY (End Interpolation) is located, in radians.

INTM = INTERVAL(Mode), the INTERVAL(Class) which contains the most frequently occurring velocity values over a RANGE INTERVAL.

GAP = GAP, the azimuthal width, in radians, separating two VELOCITYs(Range Interval Averaged), between which there is missing or bad data. Precise to 1.75×10^{-3} radians.

N = NUMBER, the number of unique Lanczos filter weights to use in actual computation.

NMV = NUMBER (Missing Velocity), number of the missing velocity in the gap for which an interpolated value is desired.

NWT = NUMBER(Weights), the number of unique Lanczos filter weights used to obtain the desired filtering characteristics. It must be an odd number with 51 currently being used in NSSL implementation.

WNOR = WEIGHT(Normalized), a member of the set of Lanczos filter weights normalized by WEIGHT(Sum).

RCI = RANGE (Center Interval), the RANGE at the center of a RANGE INTERVAL i.e., the RANGE (Slant) corresponding to a VELOCITY (Filtered) or a VELOCITY (Range Interval Averaged). Precise to .1m.

VA = VELOCITY (Azimuthal Derivative), the filtered velocity about which a centered difference approximation of AZIMUTHAL derivative is to be computed.

VBI = VELOCITY (Begin Interpolation), a valid VELOCITY (Range Interval Averaged) (i.e., not equal to DATA (Bad)) encountered at a RANGE (Center Interval) after which missing velocity values are encountered as AZIMUTH is incremented.

VEI = VELOCITY (End Interpolation), a valid VELOCITY (Range Interval Averaged) at a RANGE (Center Interval) which is ecountered just after missing velocity value as AZIMUTH is incremented.

VNUM = VELOCITY(Number in Interval), the number of VELOCITYs(Doppler) which fall into each INTERVAL(Class) over a RANGE INTERVAL. There is one value of VELOCITY(Number in Interval) for each INTERVAL(Class).

VFL = VELOCITY FILTERED, a VELOCITY (Range Interval Averaged) which has been filtered by the low pass Lanczos filter, in km/hr.

VIN = VELOCITY (Interpolated), a VELOCITY which is estimated from VELOCITYs (Range Interval Averaged), and is thereafter considered to be part of that set of velocities.

VFLaft = After VELOCITY FILTERED, the VELOCITY FILTERED immediately after VELOCITY (Azimuthal Derivative) as AZIMUTH is incremented.

VFLbef = Before VELOCITY FILTERED, the VELOCITY FILTERED immediately before VELOCITY (Azimuthal Derivative).

VRA = VELOCITY (Range Interval Averaged), the average velocity over a RANGE INTERVAL, in km/hr.

DAZ = DERIVATIVE(Azimuthal), the azimuthal derivative of the Doppler estimated radial velocity (transverse component), in (km/hr)(1/radians).

VELINC = VELOCITY(Interval Center), the VELOCITY(Doppler) at the center of an INTERVAL(Class), in km/hr.

VELMN = VELOCITY(Minimum Class Interval), the minimum (or beginning) VELOCITY (Doppler) in an INTERVAL(Class), in km/hr.

VELMX = VELOCITY(Maximum Class Interval), the largest (or ending) VELOCITY (Doppler) in an INTERVAL(Class), in km/hr.

WDR = WIND(Direction), the wind direction estimated from the SECTORIZED UNIFORM WIND (027) algorithm, valid over a volume of space defined by one set of AZIMUTHS(Filtered Velocities) and a RANGE INTERVAL. Precise to 10^{-3} radians.

INW = INTERVAL(Width), the width of a class interval for determining an average velocity in a RANGE INTERVAL. Precise to .36 km/hr.

INC = INTERVAL(Class), one of a set of intervals into which VELOCITYs (Doppler) are divided in order to determine first, the model (or most frequent value), and then the average value of the VELOCITY(Doppler) over RANGE INTERVAL. Each INTERVAL(Class) has a width of INTERVAL(Width). Precise to .1m/s.

WTLF = WEIGHT(Lanczos Filter), the filtering weights which are determined according to the Lanczos Filtering scheme.

WME = WIND(Meteorological Direction), the wind direction, in degrees, according to meteorological convention.

WSP = WIND SPEED, the velocity estimate from the SECTORIZED UNIFORM WIND (027) algorithm, valid over a sector consisting of one set of AZIMUTHS (Filtered Velocities) and a RANGE INTERVAL. Precise to .1m/sec.

WTS = WEIGHT (Sum), the sum of the Lanczos FILTER weights.

PI# = PI, a mathematical constant (3.1416), unitless.

Note: Precision will be units specified unless otherwise stated.

3.2.2 SYMBOLIC FORMULAS

COMPUTE (VELOCITY (Range Interval Averaged))

Take IM to be the number of the INTERVAL(Mode) in a RANGE INTERVAL (i.e. if the INTERVALs(Class) are numbered from 1-15 in a RANGE INTERVAL and the modal value occurs in the 9th INTERVAL(Class), IM=9). The average value of the velocity over the RANGE INTERVAL will be determined from velocities in the INTERVALs (Class) which lie on either side of the INTERVAL(Mode) and extend

$$k = \text{NINT}\ (3ms^{-1}/\text{INTERVAL(Width)})$$

where NINT denotes finding the nearest integer. Thus, if we index INTERVALs(Class) by j:

$$VRA = \sum_{j = IM-k}^{IM + k} (VELINC)_j \ (VNUM)_j \ / \sum_{j = IM-k}^{IM + k} (VNUM)_j$$

COMPUTE (GAP)

$GAP = AZendi - AZbegi$

COMPUTE (VELOCITY (Interpolated))

$$VIN = VBI + \frac{VEI - VBI}{GAP} (NMV)$$

COMPUTE (VELOCITY(Number in Interval))

VNUM is the number of valid Doppler velocities which fall into each INTERVAL(Class) in a RANGE INTERVAL.

Note: The number of INTERVALs(Class) in a RANGE INTERVAL is determined by dividing the maximum and minimum VELOCITYs(Doppler) in the RANGE INTERVAL by the INTERVAL (Width).

COMPUTE (DERIVATIVE (Azimuthal))

$DAZ = (VFLaft - VFLbef) /[(AFLaft - AFLbef)]$

COMPUTE (WIND SPEED)

$$WSP = [(VA)^2 + (DAZ)^2]^{1/2}$$

COMPUTE (WIND (Direction))

$$WDR = [\tan^{-1}] (DAZ/VA)(180/\pi) + ((AZIMUTH)180/\pi) + 180) \quad \text{IF } VA > 0$$

$$WDR = [\tan^{-1}] (DAZ/VA)(180/\pi) + ((AZIMUTH)180/\pi) \quad \text{IF } VA < 0$$

$$WDR = \begin{bmatrix} -\pi/2 \text{ IF } DAZ < 0 \\ +\pi/2 \text{ IF } DAZ > 0 \end{bmatrix} + ((AZIMUTH)180/\pi) + 180 \quad \text{IF } VA = 0$$

COMPUTE (WIND(Meteorological Direction))

$WME = MODULUS (WDR, 360)$

COMPUTE (WEIGHT(Lanczos Filter))

$$WTLF_0 = 2FC,\ k = 0$$

$$WTLF_k = \left[\frac{\sin(2\pi(FC)(k))}{(\pi k)}\right]\left[\frac{\sin((\pi k)/N)}{(\pi k)/N}\right] \quad k=(1,N)$$

where k is the number of the weight in the set ranging from 0 to N which is currently being computed.

COMPUTE (WEIGHT (SUM))

$$WTS = WTLF_0 + 2\left(\sum_{k=1}^{N} WTLF_k\right)$$

where $WTLF_0$ is the first WEIGHT(Lanczos Filter) in the set.

COMPUTE (WEIGHT(Normalized))

$$WNOR_k = WTLF_k/WTS$$

COMPUTE (VELOCITY FILTERED)

Take k to be the number of the AZIMUTH at which one computes VFL (ranging from 1-360 for 1° spaced data). Then if there are no VELOCITYs (Range Interval Averaged) in the interval extending from AZIMUTH $_{k-N}$ to AZIMUTH $_{k+N}$ equal to DATA(Bad), VELOCITY FILTERED and AZIMUTH number k is computed by:

$$VFL_k = (VRA_k)(WNOR)_0 + \sum_{j=1}^{N} (\bar{VRA}_{k-j} + VRA_{k+j})\ (WNOR)_j$$

otherwise,

$$VFL_k = DATA(Bad)$$

4.0 OUTPUTS

4.1 IDENTIFICATION

The algorithm outputs consist of a set of windspeeds and directions spaced approximately every 7 kilometers in RANGE and at the azimuths specified in AZIMUTHS (Filtered Velocities) for each full AZIMUTH sweep processed.

4.2 DISTRIBUTION

These analyzed wind fields may be readily displayed in vector or barb format, overlaid by various geographic maps, or contoured. Vertical profiles of the horizontal wind may also be constructed.

5.0 INFERENCES

5.1 LIMITATIONS

The assumption of uniformity limits the applicability of the algorithm. As discussed by Easterbrook (1975), a linear wind field will bias the estimates of the transverse component. The bias in the transverse component is $R[\zeta - \partial v_\theta/\partial r]$ where R is the RANGE, ζ is the vorticity, and $\partial v_\theta/\partial r$ is the range derivative of the transverse wind component. Thus, for RANGES of 10^5m, $\zeta - \partial v_\theta/\partial r$ must be less than 10^{-5} s^{-1} for the bias in the transverse component to be less than $\pm 1 m s^{-1}$. Some external information is needed to assess the accuracy of the analysis.

For the typical mid-latitude front, winds are close to uniform on either side of the front. However, estimates along the front can be seriously contaminated by vorticity. The algorithm is formulated for low elevation angles and the vertical component $w \sin\theta_e$ has been neglected. The application of a running weighted average filter limits the locations where estimates can be made when data are missing. For example, with NWT = 51 and an AZIMUTH spacing of 1°, the first estimate is made at 25° from the end of the data (on the circular arc).

5.2 FUTURE DEVELOPMENTS

The usefulness of the algorithm would be improved by reducing the vorticity contamination problem. Some possibilities are adding external information such as the pressure field or recognizing vortex centers. For example, at the center of a vortex the transverse component is zero and the AZIMUTHAL derivative is proportional to the vorticity (assuming a symmetric vortex). It may be possible to correct for vorticity at the other locations based on the center vorticity and the diameter of the vortex.

The second azimuthal derivative of V_r provides some information on some of the nonuniformities in the wind field. However, evaluation of the second derivative gives no indication as to the extent to which the transverse component estimate is biased. Research on the use of the second derivative for quality checking is in progress.

The current algorithm uses a weighted average filter. A recursive filter could be used which would decrease the memory and computational requirements while possibly reducing the number of weights.

GUST FRONT DETECTION

ALGORITHM DESCRIPTION

NX-DR-03-029/03

.0 PROLOGUE

1.1 FUNCTIONAL DESCRIPTION

The GUST FRONT DETECTION algorithm utilizes pattern recognition techniques to detect shear lines associated with gust fronts. This algorithm defines a process used for searching through Doppler velocity data for large gradients (Shears) along radials. Intense fronts propagating toward or away from the Doppler radar system produce at low levels a very well defined line of convergent radial velocities. For most orientations of the gust front except when it is parallel to a radial, a Doppler radar would detect convergence as a decrease in the velocities along a radial. However, fronts parallel to radials do not produce radial convergence signatures. To detect such fronts the mesocyclone-shear detection algorithm must be used.

The GUST FRONT DETECTION algorithm locates gust fronts using the following systematic procedure. The algorithm defines a technique that first computes a five point running mean and uses these means to search for runs of decreasing Doppler velocities ("radial pattern vectors") along each radial. Radial pattern vectors are obtained by using a seven point "look-ahead" capability. This procedure compares the next seven radially adjacent velocities by selecting the most positive velocity that is less than or equal to the current velocity, or "maximum", and labelling it the new "maximin". This procedure is repeated until the next seven velocities increase along the radial. These radial pattern vectors are then checked against shear and flux thresholds. Runs that pass these thresholds are sorted according to proximity to each other, length, and vertical extent and grouped into convergence features.

1.2 SOURCE

The GUST FRONT DETECTION algorithm has been developed by H. Uyeda and D. Zrnic at the National Severe Storms Laboratory (NSSL) Norman, Oklahoma.

REFERENCES

Uyeda, H., and Zrnic, D.S., 1984: Automatic Detection Of Gust Fronts. FAA Technical Report.

1.3 PROCESSING ENVIRONMENT

The algorithm requires Doppler radial velocity data which has been dealiased. However, measurement of convergence is sensitive only to the difference of velocities; therefore, improper dealiasing will not affect convergence measurements as long as the error is consistent.

2.0 INPUTS

2.1 IDENTIFICATION

AZIMUTH = Azimuthal position, in radians.

ELEVATION = Elevation angle, in radians.

MAXIMUM DISTANCE FEATURE(Convergence) = A value that represents the maximum horizontal distance that a FEATURE (Convergence) center can travel between two volume scans (5.0), in kilometers.

REFLECTIVITY FACTOR (DBZE) = The effective radar reflectivity factor of a SAMPLE VOLUME, in dBZe.

SAMPLE VOLUME = A data sample volume whose dimensions are 1 degree in azimuth, .25 km in range, and 1 degree in depth (perpendicular to the radar beam).

THRESHOLD (Convergence Azimuth) = A value that represents the maximum azimuthal separation between PATTERN VECTORs (Radial) (4), in degrees.

THRESHOLD (Convergence Range) = A value that represents the maximum range separation between PATTERN VECTORs (Radial) (4.0), in kilometers.

THRESHOLD (High Covergence Flux) = A value that represents the minimum magnitude of flux expected in convergence in the presence of minimal shear (360), in km^2/hr.

THRESHOLD (High Gradient) = A value that represents the minimum magnitude of Doppler velocity gradient in the presence of minimal convergence flux (2.34), in (km/hr)/km.

THRESHOLD (Low Convergence Flux) = A value that represents the minimum magnitude of flux expected in convergence (108), in km^2/hr.

THRESHOLD (Low Gradient) = A value that represents the minimum magnitude of Doppler velocity gradient (1.8), in (km/hr)/km.

THRESHOLD (Velocity Number) = The number of Doppler velocities used to calculate running averages (5), in km/hr.

THRESHOLD (Velocity Reflectivity) = The REFLECTIVITY FACTOR (DBZE) above which Doppler velocities will be processed (15), in dBZe.

THRESHOLD (PATTERN VECTOR (Radial) Number) = The minimum number of PATTERN VECTORs (Radial) to comprise a feature (10).

VELOCITY (Doppler) = Doppler velocities in a SAMPLE VOLUME, in km/hr.

2.2 ACQUISITION

AZIMUTH and ELEVATION are acquired as measured from the radar's instantaneous position during radial data collection.

REFLECTIVITY FACTOR (DBZE) and VELOCITY (Doppler) are acquired directly from the Doppler radar hardware.

THRESHOLD (Convergence Azimuth), THRESHOLD (Convergence Range), THRESHOLD (High Convergence Flux), THRESHOLD (High Gradient), THRESHOLD (Low Convergence Flux), THRESHOLD (Low Gradient), THRESHOLD (Velocity Number), THRESHOLD (Velocity Reflectivity), MAXIMUM DISTANCE FEATURE(Convergence) and THRESHOLD (PATTERN VECTOR (Radial) Number) are operator supplied adaptable parameters whose values are based on empirical/theoretical studies.

3.0 PROCEDURE

3.1 ALGORITHM

```
BEGIN ALGORITHM (GUST FRONT DETECTION)

1.0  DO FOR ALL (ELEVATIONs below 2 km)
     1.1  DO FOR ALL (AZIMUTHs)
          1.1.1  DO FOR ALL (SAMPLE VOLUMEs)
                 1.1.1.1  IF (The number of VELOCITYs (Doppler)
                             is greater than THRESHOLD (Velocity
                             Number))
                             THEN
                              COMPUTE (average VELOCITY(Doppler))
                          END IF
                 END DO
                 The first MAXIMIN is the very first average
                 Doppler VELOCITY with REFLECTIVITY FACTOR
                 (DBZE) greater than THRESHOLD (Velocity
                 Reflectivity)
                 DO FOR ALL (SAMPLE VOLUMEs)
                    IF (REFLECTIVITY FACTOR (DBZE) is
                       greater than THRESHOLD (Velocity Reflec-
                       tivity))
                      THEN
                        IF (One of the next seven average Doppler
                           VELOCITYs is less than or equal to
                           MAXIMIN AND is the largest average
                           Doppler VELOCITY of the seven
                           THEN (Average Doppler VELOCITY is the
                                new MAXIMIN)
                             ELSE (MAXIMIN is the current VELOCI-
                                  TY (Doppler))
                                  COMPUTE (GRADIENT)
                                  COMPUTE (GRADIENT (maximum))
                                  COMPUTE (FLUX (Convergence))
                                  IF (GRADIENT is greater than
                                     THRESHOLD (Low Gradient)
                                     AND FLUX (Convergence) is
                                     greater than THRESHOLD (High
                                     Convergence Flux)) OR (GRAD-
                                     DIENT is greater than
                                     THRESHOLD (High Gradient)
                                     AND FLUX (Convergence) is
                                     greater than THRESHOLD (Low
                                     Convergence Flux))
                                THEN (Save this set of
                                MAXIMINs in PATTERN VECTOR
                                (Radial)
                                   WRITE (GRADIENT)
                                   WRITE (GRADIENT (maxi-
                                         mum))
                                   WRITE (FLUX (Conver-
                                         gence))
                              END IF
                    END IF

              END IF
            END DO
     END DO
1.2  DO FOR ALL (PATTERN VECTORs (Radial))
     1.2.1  IF (PATTERN VECTOR (Radial) centers are within
               THRESHOLD (Convergence Range) AND THRESHOLD
               (Convergence Azimuth) of each other)
               THEN (Include PATTERN VECTORs (Radial) as
                    part of the same FEATURE)
            END IF
     END DO
1.3  DO FOR ALL (FEATURES)
     1.3.1  IF (The number of PATTERN VECTORs (Radial) is
               greater than or equal to THRESHOLD (PATTERN
               VECTOR (Radial) NUMBER)
               THEN
                   COMPUTE (FEATURE CENTER (Azimuth))
                   COMPUTE (FEATURE CENTER (Slant Range))
                   COMPUTE (maximum CONVERGENCE (Radial))
                   COMPUTE (average CONVERGENCE (Radial))
                   COMPUTE (maximum VELOCITY (Doppler)
                           DIFFERENCE)
                   COMPUTE (average VELOCITY (Doppler)
                           DIFFERENCE)
                   COMPUTE (average GRADIENT (Maximum))
                   COMPUTE (average FLUX)
                   COMPUTE (maximum FLUX)
                   COMPUTE (LENGTH (Azimuthal))
                   COMPUTE (average WIDTH)
                   COMPUTE (AREA)
                   IF (LENGTH (Azimuthal) is greater than
                      twice the average WIDTH)
```

```
                           THEN (FEATURE (Convergence) character-
                                izes a gust front)
                           ELSE (FEATURE TYPE is line shear)
                        END IF
                        IF (DIRECTION(Feature) is negative)
                           THEN (PATTERN VECTORs(Radial) compris-
                                ing FEATUREs(Convergence) that
                                lie on the same radial are
                                separated (all PATTERN VECTORs
                                along common radials with centers
                                farthest from the radar are
                                taken out of the FEATURE) and
                                classified as a secondary surge.)
                           ELSE (PATTERN VECTORs(Radial) com-
                                prising FEATUREs(Convergence)
                                that lie on the same radial are
                                separated (all PATTERN VECTORs
                                along common radials with centers
                                closest to the radar are taken
                                out of the FEATURE) and classi-
                                fied as secondary surge.)
                        END IF
                        WRITE (FEATURE (Convergence) TYPE)
                        WRITE (FEATURE (Convergence) CENTER
                              (Azimuth))
                        WRITE (FEATURE (Convergence) CENTER
                              (Range))
                        WRITE (average GRADIENT (Maximum))
                        WRITE (average FEATURE FLUX)
                        WRITE (maximum FEATURE FLUX)
                 END IF
          END DO
     END DO

2.0  DO FOR ALL (ELEVATIONs)
      2.1  DO FOR ALL (Remaining unclassified FEATUREs at the
                      current scan)
           2.1.1  DO FOR ALL (Remaining unclassified FEATUREs at
                             the previous scan)
                     COMPUTE (DIFFERENCE (Between Feature (Con-
                             vergence) centers)
                     IF (DIFFERENCE (Between Feature (Conver-
                        gence) Centers) is less than or equal to
                        MAXIMUM DISTANCE FEATURE(Convergence)
                        THEN (FEATURE (Convergence) TYPE is gust
                             front)
                        ELSE (FEATURE (Convergence) TYPE may be a
                             gust front)
                     END IF
                     WRITE (FEATURE (Convergence) TYPE)
                  END DO
           END DO
     END DO

    END ALGORITHM (GUST FRONT DETECTION)
```

3.2 COMPUTATION

3.2.1 NOTATION

AFE = AREA, the area of a FEATURE, in km^2.

FCAZ = FEATURE CENTER (Azimuth), the FEATURE center position, in azimuth.

AZPO = AZIMUTH POSITION, the position of a point in a FEATURE, in azimuth.

VDavg = average VELOCITY (Doppler), the smoothed 5 point average Doppler Velocity. in km/hr.

FEAC = FEATURE (Convergence), a set of PATTERN VECTORs (Radial) in close spatial proximity.

PVER = PATTERN VECTOR (Radial), the vector which is formed when a run of decreasing Doppler velocity ends. A PATTERN VECTOR (Radial) contains six components: the beginning and ending Doppler velocity, beginning and ending range, azimuth, and maximum gradient.

RCavg = average RADIAL CONVERGENCE, the average radial convergence in a FEATURE, in 1/hr.

VDDavg = average VELOCITY (Doppler) DIFFERENCE, the average Doppler velocity difference of a FEATURE, in km/hr.

FVVC = FLUX (Convergence), the flux of a PATTERN VECTOR (Radial), in km^2/hr.

FFavg = average FEATURE FLUX, the average flux of a FEATURE, in km^2/hr.

G = GRADIENT, the gradient of a PATTERN VECTOR (Radial), in 1/hr.

Gmax = maximum GRADIENT, the maximum gradient of a 5 point section of a PATTERN VECTOR (Radial) in 1/hr.

RC = RADIAL CONVERGENCE, the radial convergence in a FEATURE, in 1/hr.

Gavgmax = average of the maximum GRADIENT, the average of the maximum gradients of the PATTERN VECTORs (Radial) which comprise a FEATURE, in 1/hr.

LAZ = LENGTH (Azimuthal), the length along an azimuth of a FEATURE, in km.

NVV = NUMBER of PATTERN VECTORs (Radial), the number of PATTERN VECTORs (Radial) comprising a possible FEATURE.

RCmax = maximum RADIAL CONVERGENCE, the maximum radial convergence in a FEATURE, in 1/hr.

MAXIMIN = MAXIMIN, the highest of seven adjacent Doppler velocities, which is less than or equal to the current velocity.

VDDmax = maximum VELOCITY (Doppler) DIFFERENCE, the maximum velocity difference of a FEATURE, in km/hr.

FFmax = maximum FEATURE FLUX, the maximum FLUX of a FEATURE, in km^2/hr.

RSVVbeg = beginning RANGE (Slant-Gust Front), the beginning slant range of a PATTERN VECTOR (Radial), in kilometers.

RSVVend = ending RANGE (Slant-Gust Front), the ending slant range of a PATTERN VECTOR (Radial), in kilometers.

FCRS = FEATURE CENTER (Slant-Range), the FEATURE center position, in range.

VDini = initial VELOCITY (Doppler), the smoothed 5 point average Doppler velocity at the beginning of a PATTERN VECTOR (Radial), in km/hr.

VDfin = final VELOCITY (Doppler), the smoothed 5 point average Doppler velocity at the end of a PATTERN VECTOR (Radial), in km/hr.

RSVV = RANGE (Slant-Gust Front), the slant ranges of a PATTERN VECTOR (Radial), in kilometers.

WI = WIDTH, the width of a FEATURE, in kilometers.

WIavg = average WIDTH, the average width of a FEATURE, in km.

PI# = PI#, a mathematical constant (3.1416), unitless.

Precisions are equivalent to the units specified except for the high and low gradient THRESHOLDS, which must be precise to 0.01 (km/hr)/km.

NOTE: The intermediate computations need to be done in floating point single precision to avoid accumulative round-up errors.

3.2.2 SYMBOLIC FORMULAS

COMPUTE (AREA)

$$AFE = \frac{\pi}{720} \sum (AZPO_{1+1} - AZPO_i)(RSVVbeg + RSVVend)_i$$

$$[(RSVVend - RSVVbeg)_i + (RSVVend - RSVVbeg)_{i+1}]$$

COMPUTE (FEATURE CENTER (Azimuth))

$$FCAZ = \frac{1}{NVV} \sum AZPO_i$$

COMPUTE (FEATURE CENTER (Slant Range))

$$FCRS = \frac{1}{2NVV} \sum (RSVVbeg + RSVVend)_i$$

COMPUTE (FLUX (Convergence))

$$FVVC = (VDini - VDfin)(RSVVend - RSVVbeg)$$

COMPUTE (average FEATURE FLUX)

$$FFave = \frac{1}{NVV} \sum [(VDini - VDfin)(RSVVend - RSVVbeg)]_i$$

COMPUTE (maximum FEATURE FLUX)

$$FFmax = \max[(VDini - VDfin)(RSVVend - RSVVbeg)]_i$$

COMPUTE (GRADIENT)

$$G = \frac{VDini - VDfin}{RSVVend - RSVVbeg}$$

COMPUTE (maximum GRADIENT) within a PATTERN VECTOR(Radial).

$$G_{max} = \max\left(\frac{VD_{n-2} - VD_{n+2}}{RSVV_{n+2} - RSVV_{n-2}} \right)$$

COMPUTE (average of the maximum GRADIENT) within a FEATURE

$$Gavgmax = \frac{1}{NVV} \sum Gmax_i$$

COMPUTE (LENGTH(Azimuthal))

$$LAZ = \left(\left[\frac{\pi}{360}(AZPO_{i+1} - AZPO_i)(RSVVbeg + RSVVend)_i\right]^2 + \left[(RSVVbeg + RSVVend)_{i+1} - (RSVVbeg + RSVVend)_i\right]^2/4\right)^{1/2}$$

COMPUTE (average RADIAL CONVERGENCE)

$$RCavg = \frac{1}{NVV} \sum \left(\frac{VDini - VDfin}{RSVVend - RSVVbeg} \right)_i$$

COMPUTE (average VELOCITY(Doppler))

$$VDavg = \frac{1}{5} \sum_{i=1}^{5} VD_i$$

COMPUTE (maximum RADIAL CONVERGENCE)

$$RCmax = \max\left(\frac{VDini - VDfin}{RSVVend - RSVVbeg} \right)_i$$

COMPUTE (average VELOCITY (Doppler) DIFFERENCE)

$$VDDavg = \frac{1}{NVV} \sum (VDfin - VDini)_i$$

COMPUTE (maximum VELOCITY (Doppler) DIFFERENCE)

$VDDmax = max(VDfin - VDini)_i$

COMPUTE (average WIDTH)

$$Wavg = \frac{1}{NVV} \sum (RSVVend - RSVVbeg)_i$$

Note: The following quantities are computed over all PATTERN VECTORs (Radial) within a specific FEATURE: AFE, FCAZ, FCRS, FFave, Gavgmax, LAZ, RCavg, VDDavg and Wavg.

The following maximum values were computed over all PATTERN VECTORs (Radial) within a specific FEATURE: FFmax, RCmax, and VDDmax.

Gmax is the maximum within one specific PATTERN VECTOR(Radial).

4.0 OUTPUTS

4.1 IDENTIFICATION

The outputs of this algorithm describe characteristics of convergence that are used to determine the location of gust fronts. The outputs are: AREA (Feature), CENTER (Azimuth), CENTER (Slant Range), FLUX, average FEATURE FLUX, Maximum FEATURE FLUX, GRADIENT, maximum GRADIENT, average of the maximum GRADIENT, LENGTH of the FEATURE, average RADIAL CONVERGENCE, maximum RADIAL CONVEGGENCE, average VELOCITY (Doppler) DIFFERENCE, maximum VELOCITY (Doppler), average WIDTH of the FEATURE.

4.2 DISTRIBUTION

The outputs of this algorithm could be used in severe weather warning procedures.

.0 INFERENCES

5.1 LIMITATIONS

No major limitations are noted at this time.

5.2 FUTURE DEVELOPMENTS

Much work remains to be done before this algorithm can be put into operational use. Presently, this algorithm cannot detect gust fronts that are parallel to radials. To detect such fronts the mesocyclone-shear detection technique must be incorporated into this algorithm.

FLASH FLOOD PRECIPITATION PROJECTION

ALGORITHM DESCRIPTION

NX-DR-03-030/05

.0 PROLOGUE

1.1 FUNCTIONAL DESCRIPTION

The primary purpose of the FLASH FLOOD PRECIPITATION PROJECTION algorithm is to produce short-term forecasts of precipitation accumulations updated at scan rate intervals for up to one hour into the future. The algorithm also produces observed and total (observed and projected) storm precipitation accumulations for up to six hours, and associated error variances. These projections, accumulations, and error variances are then input to the FLASH FLOOD POTENTIAL ASSESSMENT algorithm. The FLASH FLOOD PRECIPITATION PROJECTION algorithm uses the current precipitation rate (RATE SCAN) data set output by the PRECIPITATION RATE algorithm and the adjusted ACCUMULATION SCAN (Scan-to-Scan) output by the PRECIPITATION ADJUSTMENT algorithm. Using a statistical forecasting approach, the FLASH FLOOD PRECIPITATION PROJECTION algorithm determines mean storm dynamics, normalized residual and residual persistence, precipitation initiation times, precipitation rate projections, precipitation accumulations, and error variances.

The mean storm dynamics refers to the expected value of precipitation rate, and its standard deviation, at any point in space or time. The mean storm dynamics are assumed to be the same at every spatial location in a time coordinate system measured relative to the time of precipitation initiation at each location. The sample used to estimate the mean storm dynamics is all observed precipitation rates for which the time since the initiation of precipitation at each point is identical. The mean and standard deviation are then simply the average and standard deviation of this sample. Simple persistence will be used to project the storm dynamics into the future.

The residual is defined as the difference between the observed precipitation rate and the mean value of the precipitation rate for each bin in an observed scan. The normalized residual is the residual divided by the standard deviation. The residual persistent is determined by a normalization procedure which allows the residuals to be directly compared from one scan to the next to derive a single parameter residual decay.

Precipitation initiation times are a function of storm velocity (leading edge) and direction. The estimation of the time of initial precipitation at locations where precipitation has not yet commenced is defined by the difference between that location and the closest "upwind" point where precipitation is occurring, divided by the storm speed.

The projected precipitation rate is the mean rate plus the projected normalized residual multiplied by the standard deviation. The projected precipitation determines the precipitation rates at selected time intervals into the future, for up to one hour. Projected accumulations are based on these projected rates.

In addition to the projected precipitation accumulation there are also the total observed precipitation accumulation and the total storm precipitation accumulation. The observed precipitation accumulation is the summation of the scan-to-scan accumulations obtained rom the PRECIPITATION ADJUSTMENT algorithm. The total storm precipitation is the addition of the total observed accumulation with the projected precipitation accumulation. Error variances are calculated for all precipitation accumulations.

1.2 SOURCE

The FLASH FLOOD PRECIPITATION PROJECTION algorithm was developed by the Radar Hydrology Group of the National Weather Service's Hydrologic Research Laboratory. This algorithm has been based on experiences gained through the use of real-time rainfall estimation from the D/RADEX system, the GATE project, and other experimental projects as well as an in-depth analysis of ways with which weather radar data could be better used for hydro-meterological purposes.

1.3 PROCESSING ENVIRONMENT

This algorithm must keep track of many variables over an entire precipitation event. Loss of any information during this time will seriously damage its operation. Therefore, the methods used to save these variables must be safe from temporary system shutdowns and restarts.

The Limited Fine Mesh (LFM) grid is a rectangular grid commonly used by the National Weather Service which is based on a polar stereographic projection. An LFM grid box represents an area whose size and shape varies with latitude. Therefore the size and shape of the grid boxes will vary slightly over the area covered by the radar and even more from radar to radar. The orientation and mesh length of the LFM grid is designed to contain the NWS Manually Digitized Radar (MDR) and the National Weather Service River Forecast System (NWSRFS)/Hydrologic Rainfall Analysis Project (HRAP) grids as subsets. The MDR grid mesh length is 1/4th the length of the LFM grid mesh. The NWSRFS/HRAP grid mesh length is 1/40th and 1/10th the lengths of the LFM and MDR grid mesh, respectively. As a result, the MDR grid is commonly referred to as the 1/4th LFM Grid and the NWSRFS/HRAP grid is often called the 1/40th LFM Grid. The grid mesh lengths of the LFM, 1/4th LFM and 1/40th LFM at 60° N latitude are 190.5 km, 47.625 km and 4.7625 km, respectively. The information required to generate the grid for each site are the latitude and longitude of the radar, and the mesh length at 60° N (the standard latitude) and 105° W (the standard longitude).

In order to cover the radar umbrella out to 230 km, especially in the lower latitudes of the conterminous U.S., a 131 by 131 array of 1/40th LFM grid boxes will be required. This array will always be 131 by 131 regardless of the site latitude. The grid should be positioned in such a way that the radar site falls within the grid box (66,66). In this algorithm a simple coordinate system is used to define the x and y coordinates of the ith grid as its grid location (from 1 to 131) minus 66.
Generally rainfall rates or accumulations can be retained in two types of units. The more familiar linear units are in mm (for accumulations) or mm/hr (for rates). Logarithmic units can also be used (dBA for accumulations, dBR for rates). The storage requirements for the logarithmic units are approximately one-half that for linear units (about 8 bits/value as opposed to 16 bits/value). However, several computations must be done in linear units which necessitates conversions from logarithmic to linear units (and vice vesa) if logarithmic units are used. Since these conversions incure a penalty on CPU time, this algorithm is written in linear units.

Wherever a power of 10 or base 10 logarithm is found in these algorithms, a conversion from logarithmic units to linear units or vice versa is taking place. This conversion can be done by actually computing the powers and logarithms at each sample volume or through the use of a computation saving technique such as the use of a discrete conversion table or any other technique providing sufficient precision. The use of dBRs and dBAs is intended to reduce storage requirements while maintaining required precision at the small end of the scale. However, as long as the requested precision at the small end of the scale is maintained, some CPU time may be saved by keeping the data in linear (mm/hr or mm) units at the expense of increases in storage requirements.

If the data are kept in units of mm/hr or mm the computational steps must be appropriately modified to remove the conversions which are no longer needed. The units used for external communications should be chosen on the basis of communications requirements (e.g. dBA's for the ARRAY PRODUCT (Digital Precipitation)) regardless of the units used for internal computations.

2.0 INPUTS

2.1 IDENTIFICATION

adjusted ACCUMULATION SCAN (Scan-to-Scan) = The total scan-to-scan accumulation data on a 1 degree by 2 km polar grid from 1 to 230 km in dBA. This data has been adjusted for the estimated mean field bias. Includes the previous average TIME (scan) and current average TIME (scan).

average TIME (Scan) = The average scan time of the four elevation scans used to construct the HYBRID SCAN. This is a time of occurrence, not duration.

BIAS (current) = current BIAS, the current multiplicative factor that adjusts for the radar bias when compared to surface precipitation measurements.

BOX (1/40th LFM Grid) = Rectangular grid box centered on 1/40th LFM grid points. At 60 degrees N, the mesh length is 4.7625 km. Specifies the Scan's sample volumes whose centers fall within each grid box. If none, the sample volume whose center is closest to the center of the grid box is specified. Grid boxes whose centers are more than 230 km from the radar are not assigned to any sample volumes.

ERROR (Proportion Factor) = Ratio of presumed observational error variance of precipitation rates to local (5 x 5 grids) variance of precipitation rates themselves, unitless.

FLAG (Zero Rate) = A set or cleared flag for each average TIME (Scan) indicating, if set, that all precipitation rate values can be assumed to be equal to RATE (Zero Precipitation).

FLAG (Zero Scan-to-Scan) = A set or cleared flag indicating, if set, that all current ACCUMULATION SCAN (Scan-to-Scan) values can be assumed to be equal to ACCUMULATION (Zero Level).

PROJECTION INTERVAL = An even multiple of the projection time step for a given projected precipitation.

RATE SCAN = Precipitation rate data on a 1 degree by 2 km polar grid from 1 to 230 km, in dBR.

STORM INITIATION WIDTH = This is the width of the rectangular region (searched "upwind") for storm initiation measured in units of grid spacing.

STORM INITIATION DECAY = A decay parameter which determines the weight to be placed on previous storm motion information.

THRESHOLD (Minimum NUMBER of SAMPLES) = The minimum NUMBER of SAMPLES needed for a valid statistical analysis.

TIME (Last Precipitation Detected) = The time at which the Precipitation Detection support function last detected precipitation. A precision of at least 1/1200 hour is required.

TIME (Reset) = Maximum time allowed for no precipitation before parameters are reset, in hours.

2.2 ACQUISITION

RATE SCANs and FLAG (Zero Rate) are obtained from the PRECIPITATION RATE algorithm.

Average TIMEs (Scan) for each RATE SCAN are obtained from the PRECIPITATION PREPROCESSING algorithm. A precision of at least 1/1200th hour and an accuracy of 1/120th hour is required.

BOX (1/40th LFM Grid) is a unit adaptation parameter file which is automatically generated given the latitude and longitude of the site, mesh length of 60° N (4.7625 km), and the reference longitude (105°W).

TIME (Last Precipitation Detected) is obtained from the Precipitation Detection support function.

TIME (Reset), STORM INITIATION WIDTH, ERROR (Proportion Factor), THRESHOLD (minimum NUMBER of SAMPLES), STORM INITIATION DECAY, and PROJECTION INTERVAL are all unit adaption parameters.

The current BIAS and adjusted ACCUMULATION SCAN (Scan-to-Scan) are obtained from the PRECIPITATION ADJUSTMENT algorithm.

FLAG (Zero Scan-to-Scan) is obtained from PRECIPITATION ACCUMULATION [019] algorithm.

.0 PROCEDURE

3.1 ALGORITHM

```
BEGIN ALGORITHM (FLASH FLOOD PRECIPITATION PROJECTION)

1.0  IF (FLAG (Zero Rate)) is set
          THEN DO FOR ALL (BOX 1/40th LFM Grid) set all adjusted
               RATEs (Precipitation) to zero
               END DO
          ELSE
              DO FOR ALL (BOX (1/40th LFM Grid))
                   COMPUTE (adjusted RATE (Precipitation))
              END DO
     END IF

2.0  IF (average TIME (Scan) minus TIME (Last Precipitation
        Detected) is greater than TIME (Reset))
        THEN
              Set COUNTER (Storm) to zero for all boxes
              Set maximum COUNTER (Storm) to zero
              Set total RATE (Precipitation) to zero for all
                  COUNTERs (Storm)
              Set squared total RATE (Precipitation) to zero for
                  all COUNTERs (Storm)
              Set NUMBER of SAMPLES to zero for all COUNTERs
                  (Storm)
              Set STORM INITIATION SUM 1 through STORM INITIATION
                  SUM 8 to zero.
              Set sum of grid box observed ERROR VARIANCE to zero
                  for all BOXES (Also discard all previously saved
                  values)
              Set total observed PRECIPITATION ACCUMULATION
                  to zero for all BOXES (Also discard all pre-
                  viously saved values).
              Set FLAG (No Projection)
              STOP Projection Procedure and restart at next scan
        ELSE
              Clear FLAG (No Projection)
     END IF

3.0  IF FLAG (Zero Scan-to-Scan) clear

        THEN
             DO FOR ALL (BOXes (1/40th LFM Grid))
                  COMPUTE (total observed PRECIPITATION
                                ACCUMULATION)
             END DO
        ELSE
          total observed PRECIPITATION ACCUMULATION remains
          unchanged
     END IF
     WRITE (total observed PRECIPITATION ACCUMULATION)
```

```
4.0  DO FOR ALL (BOX (1/40th LFM Grid))

     4.1  Set temporary NUMBER of SAMPLES to zero
          Set temporary total adjusted RATE (Precipitation) to
          zero
          Set temporary squared total adjusted RATE (Precipita-
          tion) to zero
          DO FOR ALL (25 BOXES (1/40th LFM Grid) centered on the
                      current BOX (1/40th LFM Grid))
                  COMPUTE (grid box SAMPLE VALUES)

          END DO
          COMPUTE (grid box observed ERROR VARIANCE)
          COMPUTE (sum of grid box observed ERROR VARIANCE)
      4.2 IF (adjusted RATE (Precipitation) for this BOX is less
             than or equal to zero)
             THEN
               IF (COUNTER (Storm) greater than 0)

                  THEN COMPUTE (TIME (Expired) for this BOX)
                    IF (TIME (Expired) for this BOX greater
                       than or equal to TIME (Reset)
                       THEN Set COUNTER (Storm) for this BOX to
                            zero
                       ELSE COMPUTE (COUNTER (Storm))
                            COMPUTE (maximum COUNTER (Storm))
                            COMPUTE (COUNTER (Storm) Sample
                                    Values)
                    END IF
               END IF
             ELSE
                 IF (COUNTER (Storm) for this BOX equals zero)
                    THEN TIME (Begin) for this BOX equals average
                         TIME (Scan)

                 END IF
             Set TIME (End) for this BOX to average TIME (Scan)
             COMPUTE (COUNTER (Storm))
             COMPUTE (maximum COUNTER (Storm))
             COMPUTE (COUNTER (Storm) Sample Values)
          END IF
     END DO

5.0  Save total observed PRECIPITATION ACCUMULATION and sum
          of grid box observed ERROR VARIANCE for each BOX
          (1/40th LFM Grid) and scan.
```

```
6.0 DO FOR ALL (Values of COUNTER (Storm) from 1 to maximum
                COUNTER (Storm))
    6.1 IF (NUMBER OF SAMPLES for this COUNTER (Storm) is
           greater than or equal to THRESHOLD (Minimum NUMBER OF
           SAMPLES))
           THEN COMPUTE (STORM DYNAMICS (Single COUNTER (Storm)
                Method))
                Set temporary NUMBER of SAMPLES equal to NUMBER
                    of SAMPLES for this COUNTER (Storm)
           ELSE Set temporary NUMBER OF SAMPLES to zero
                Set temporary total RATE (Precipitation) to zero
                Set temporary squared total RATE (Precipitation)
                    to zero
                DO FOR ALL (COUNTER (Storm) from current
                           value of COUNTER (Storm) to max-
                           imum COUNTER (Storm))
                   DO UNTIL (temporary NUMBER OF SAMPLES is
                            greater than or equal to THRESHOLD
                            (minimum NUMBER OF SAMPLES))
                      COMPUTE (temporary COUNTER (Storm) Sample
                              Values)
                   END DO
                END DO
                IF (temporary NUMBER OF SAMPLES is less than
                   THRESHOLD (Minimum NUMBER OF SAMPLES))
                   THEN DO FOR ALL (COUNTER (Storm) from
                                   from (current value of
                                   COUNTER (Storm) minus one)
                                   to one (stepping backwards))
                          DO UNTIL (temporary NUMBER OF SAMPLES
                                    is greater than or equal to
                                    THRESHOLD (Minimum NUMBER OF
                                    SAMPLES))
                                    COMPUTE (temporary COUNTER
                                            (Storm) Sample
                                            Values)
                          END DO
                       END DO
                END IF
                IF (temporary NUMBER OF SAMPLES is less than
                   THRESHOLD (Minimum NUMBER OF SAMPLES))
                   THEN Set FLAG (No projection)
                        STOP (projection procedure and restart
                            after next scan)
                   ELSE COMPUTE (STORM DYNAMICS (Multiple
                        COUNTER (Storm) Method))
              END IF
       END IF
   END DO
```

```
7.0  COMPUTE (COUNTER (Highest Storm))
8.0  DO FOR ALL (Values of COUNTER (Storm) from maximum COUNTER
                (Storm) to COUNTER (Highest Storm))
          COMPUTE (projected STORM DYNAMICS)
     END DO

9.0  Set COUNTER (Autocorrelation) to zero
     Set LAGONE AUTOCORRELATION to zero
     Set LAGZERO AUTOCORRELATION to zero
     DO FOR ALL (BOX (1/40th LFM Grid))
        IF (COUNTER (Storm) is greater than zero)
           THEN COMPUTE (NORMALIZED RESIDUAL)
        END IF
        IF (COUNTER (Storm) is greater than one)
           THEN COMPUTE (CORRELATION (Parameters))
        END IF
     END DO

10.0 SET TEMPORARY SUM 1 through TEMPORARY SUM 7 to zero

11.0 DO FOR ALL (BOX (1/40th LFM Grid) where COUNTER (Storm) is
               equal to one)
        DO FOR ALL (Surrounding 48 nearest-neighbor BOXES (1/40th
                   LFM Grid))
           IF (COUNTER (Storm) for surrounding BOX (1/40th LFM
              Grid) is greater than one)
              THEN COMPUTE (TEMPORARY SUMs)
           END IF
        END DO
     END DO

12.0 COMPUTE (STORM INITIATION SUMS)

13.0 IF (COUNTER (Autocorrelation) is less than THRESHOLD (Mini-
        mum NUMBER OF SAMPLES))
        THEN Set FLAG (No Projection)
             STOP (Projection procedure and restart at next scan)
        ELSE
             COMPUTE (PROJECTION PARAMETER)
     END IF

14.0 IF (STORM INITIATION SUM 6 is less than THRESHOLD (Minimum
        NUMBER OF SAMPLES))
        THEN Set FLAG (No Projection)
             STOP (Projection procedure and restart at next scan)
        ELSE
             COMPUTE (STORM INITIATION PARAMETERS)
     END IF
```

```
15.0 COMPUTE (STORM INITIATION OFFSET LIMITS (Y-direction))

16.0 DO FOR ALL (STORM INITIATION OFFSET (X-direction) from -131
                to +131)
        COMPUTE (maximum STORM INITIATION OFFSET (positive Y-
                direction))
        COMPUTE (maximum STORM INITIATION OFFSET (negative Y-
                direction))
        DO FOR ALL (STORM INITIATION OFFSET (Y-direction) from
                   maximum STORM INITIATION OFFSET (positive Y-
                   direction) to maximum STORM INITIATION OFFSET
                   (negative Y-direction))
           COMPUTE (STORM INITIATION OFFSET TIME)
           IF ((STORM INITIATION OFFSET Time) greater than or
              equal to zero AND (STORM INITIATION OFFSET TIME)
              less than PROJECTION INTERVAL)
              THEN (Add (offset of X, Y, and Time) to (offset
                   table))
                   (This table has the following columns)
                   1.  STORM INITIATION OFFSET TIME
                   2.  STORM INITIATION OFFSET (X-direction)
                   3.  STORM INITIATION OFFSET (Y-direction)
           END IF
        END DO
     END DO

17.0 Truncate all values of STORM INITIATION OFFSET TIME in Off-
     set table to integers.

18.0 SORT (STORM INITIATION OFFSET TABLE) in order of increasing
          STORM INITIATION OFFSET TIME

19.0 COMPUTE (maximum PROJECTION TIME COUNTER)

20.0 DO FOR ALL (Values of JINDEX from one to PRCmax)
         DO FOR ALL (Values of KINDEX from JINDEX to PRCmax)
               Set MULTMATRIX (JINDEX, KINDEX) to zero
               COMPUTE (minimum INDEX)
               Set SUM1 equal to zero
               DO FOR ALL (Values of LINDEX from zero to minimum
                           INDEX)
                      COMPUTE (SUM1)
               END DO
               COMPUTE (MULTMATRIX)
               IF (JINDEX not equal to KINDEX)
                  THEN MULTMATRIX value equals MULTMATRIX value
                       times two
               END IF
         END DO
   END DO

21.0 DO FOR ALL (BOX (1/40th LFM Grid))
        IF (COUNTER (Storm) for this BOX is greater than zero)
           THEN (Set temporary COUNTER (Storm) to COUNTER (Storm)
                Set temporary RESIDUAL (Normalized) to current
                    RESIDUAL (Normalized)).
```

```
7.0  COMPUTE (COUNTER (Highest Storm))
8.0  DO FOR ALL (Values of COUNTER (Storm) from maximum COUNTER
                (Storm) to COUNTER (Highest Storm))
           COMPUTE (projected STORM DYNAMICS)
     END DO

9.0  Set COUNTER (Autocorrelation) to zero
     Set LAGONE AUTOCORRELATION to zero
     Set LAGZERO AUTOCORRELATION to zero
     DO FOR ALL (BOX (1/40th LFM Grid))
        IF (COUNTER (Storm) is greater than zero)
           THEN COMPUTE (NORMALIZED RESIDUAL)
        END IF
        IF (COUNTER (Storm) is greater than one)
           THEN COMPUTE (CORRELATION (Parameters))
        END IF
     END DO

10.0 SET TEMPORARY SUM 1 through TEMPORARY SUM 7 to zero

11.0 DO FOR ALL (BOX (1/40th LFM Grid) where COUNTER (Storm) is
                equal to one)
        DO FOR ALL (Surrounding 48 nearest-neighbor BOXES (1/40th
                   LFM Grid))
           IF (COUNTER (Storm) for surrounding BOX (1/40th LFM
              Grid) is greater than one)
              THEN COMPUTE (TEMPORARY SUMs)
           END IF
        END DO
     END DO

12.0 COMPUTE (STORM INITIATION SUMS)

13.0 IF (COUNTER (Autocorrelation) is less than THRESHOLD (Mini-
        mum NUMBER OF SAMPLES))
        THEN Set FLAG (No Projection)
             STOP (Projection procedure and restart at next scan)
        ELSE
             COMPUTE (PROJECTION PARAMETER)
     END IF

14.0 IF (STORM INITIATION SUM 6 is less than THRESHOLD (Minimum
        NUMBER OF SAMPLES))
        THEN Set FLAG (No Projection)
             STOP (Projection procedure and restart at next scan)
        ELSE
             COMPUTE (STORM INITIATION PARAMETERS)
     END IF
```

```
15.0 COMPUTE (STORM INITIATION OFFSET LIMITS (Y-direction))

16.0 DO FOR ALL (STORM INITIATION OFFSET (X-direction) from -131
             to +131)
        COMPUTE (maximum STORM INITIATION OFFSET (positive Y-
             direction))
        COMPUTE (maximum STORM INITIATION OFFSET (negative Y-
             direction))
        DO FOR ALL (STORM INITIATION OFFSET (Y-direction) from
                   maximum STORM INITIATION OFFSET (positive Y-
                   direction) to maximum STORM INITIATION OFFSET
                   (negative Y-direction))
           COMPUTE (STORM INITIATION OFFSET TIME)
           IF ((STORM INITIATION OFFSET Time) greater than or
              equal to zero AND (STORM INITIATION OFFSET TIME)
              less than PROJECTION INTERVAL)
              THEN (Add (offset of X, Y, and Time) to (offset
                   table))
                   (This table has the following columns)
                   1.  STORM INITIATION OFFSET TIME
                   2.  STORM INITIATION OFFSET (X-direction)
                   3.  STORM INITIATION OFFSET (Y-direction)
           END IF
        END DO
     END DO

17.0 Truncate all values of STORM INITIATION OFFSET TIME in Off-
     set table to integers.

18.0 SORT (STORM INITIATION OFFSET TABLE) in order of increasing
          STORM INITIATION OFFSET TIME

19.0 COMPUTE (maximum PROJECTION TIME COUNTER)

20.0 DO FOR ALL (Values of JINDEX from one to PRCmax)
         DO FOR ALL (Values of KINDEX from JINDEX to PRCmax)
               Set MULTMATRIX (JINDEX, KINDEX) to zero
               COMPUTE (minimum INDEX)
               Set SUM1 equal to zero
               DO FOR ALL (Values of LINDEX from zero to minimum
                          INDEX)
                      COMPUTE (SUM1)
               END DO
               COMPUTE (MULTMATRIX)
               IF (JINDEX not equal to KINDEX)
                  THEN MULTMATRIX value equals MULTMATRIX value
                       times two
               END IF
         END DO
   END DO

21.0 DO FOR ALL (BOX (1/40th LFM Grid))
        IF (COUNTER (Storm) for this BOX is greater than zero)
           THEN (Set temporary COUNTER (Storm) to COUNTER (Storm)
                Set temporary RESIDUAL (Normalized) to current
                    RESIDUAL (Normalized)).
           ELSE
           DO FOR ALL (entries in STORM INITIATION OFFSET Table
                      in the sorted order)
           Set TARGET BOX to the BOX at the location of this
           1/40th LFM grid BOX plus the (X offset, Y off-
           set) from this entry in the STORM INITIATION
           OFFSET Table
              IF (TARGET BOX is outside the 131 by 131 grid)
                 THEN (skip to next entry in the STORM INITIATION
                      OFFSET Table)
              END IF
              IF (COUNTER (Storm) for the TARGET BOX is greater
                 than zero)
                 THEN Set temporary COUNTER (Storm) to the nega-
                          tive of the (STORM INITIATION OFFSET
                          TIME) from this entry in the STORM
                          INITIATION OFFSET Table
                      Set temporary RESIDUAL (Normalized) to cur-
                          rent RESIDUAL (Normalized) for TARGET
                          BOX
                      Skip to next BOX (1/40th LFM grid)
              END IF
           END DO
           Set temporary RESIDUAL (Normalized) to zero
           Set Temporary COUNTER (Storm) to a large negative num-
               ber (-100)
        END IF
     END DO

22.0 COMPUTE (Projection Times)

23.0 DO FOR ALL (Projection Times)
        COMPUTE (PROJECTION TIME COUNTERs)
     END DO

24.0 DO FOR ALL (Values of COUNTER (Storm) from negative maximum
                PROJECTION TIME COUNTER to maximum COUNTER(Storm)
           Set projected VARIANCE sum equal to zero
           DO FOR ALL (PROJECTION TIME COUNTERs from 1 to PRCmax)
                DO FOR ALL (temporary PROJECTION TIME COUNTERs
                           from current value of PROJECTION TIME
                           COUNTER to maximum PROJECTION TIME
                           COUNTER)
                           COMPUTE (projected VARIANCE sum)
                END DO
                COMPUTE (Projected VARIANCE)
           END DO
     END DO
```

```
25.0 DO FOR ALL (BOX (1/40th LFM Grid))
          Set total projected RATE (Precipitation) to zero
          COMPUTE (total PROJECTED VARIANCE)
              DO FOR ALL (Projection Times)
                   COMPUTE (PROJECTION TIME COUNTER)
                   IF (TEMPORARY COUNTER (Storm) plus PROJECTION
                      TIME COUNTER is less than or equal to zero)
                      THEN Set projected RATE (Precipitation) to
                           zero
                      ELSE COMPUTE (projected RATE (Precipita-
                                   tion))
                        IF projected RATE (Precipitation) less
                           than zero
                           THEN Set projected RATE (Precipita-
                                tion) equal to zero
                        END IF
                   END IF
                   COMPUTE (total PROJECTED RATE (Precipita-
                           tion))
              END DO
              COMPUTE (projected PRECIPITATION ACCUMULATION)
              WRITE (projected PRECIPITATION ACCUMULATION)
              COMPUTE (total storm PRECIPITATION ACCUMULATION)
              WRITE (total storm PRECIPITATION ACCUMULATION)
              COMPUTE (total VARIANCE)
              WRITE (total VARIANCE)
     END DO

END ALGORITHM (FLASH FLOOD PRECIPITATION PROJECTION)
```

3.2 COMPUTATION

3.2.1 NOTATION

$\mathrm{RR\ adj}_i$ = Adjusted RATE (Precipitation), RATE (adjusted for radar bias) of precipitation of the i-th BOX (1/40th LFM Grid) in the current scan (in mm/hr). Precise to .1 mm/hr.

Bcur = Current BIAS, the current multiplicative factor that adjusts for the radar bias when compared to surface precipitation measurements.

PAtotobs = Total observed PRECIPITATION ACCUMULATION, total observed precipitation accumulation (adjusted for the estimated mean field bias) for the i-th BOX (1/40th LFM Grid) (in mm) and associated average TIME (Scan) for each average TIME (Scan) during the past 6 hours. Precise to .1 mm/hr.

EVns_i = ERROR VARIANCE (Number of Samples), number of samples for the grid box observed error variance for the i-th BOX (1/40th LFM Grid).

RRevar_i = Error variance RATE (Precipitation), total RATE of precipitation for the 25 Boxes surrounding the i-th BOX (1/40th LFM Grid) for the grid box observed error variance (in mm/hr). Precise to .1 mm/hr.

$\mathrm{RRsqrevar}_i$ = Squared error variance RATE (Precipitation), total squared RATE (Precipitation) for the 25 Boxes surrounding the i-th BOX (1/40th LFM Grid) for the grid box observed error variance (in mm^2/hr^2). Precise to $.1mm^2/hr^2$.

ASSadj = Adjusted ACCUMULATION SCAN (Scan-to-Scan), the total scan-to-scan accumulation data on a 1 degree by 2 km polar grid from 1 to 230 km in dBA. This data has been adjusted for the estimated mean field bias. A precision of at least 0.5 dBA and dynamic range of at least -29 to +26 dBA are required. Includes the previous average TIME (Scan) and current average TIME (Scan).

EPF = ERROR (Proportion Factor), ratio of presumed observational error variance of precipitation rates to local (5 x 5 grids) variance of precipitation rates themselves, unitless.

EV_i = Grid box observed ERROR VARIANCE, the observed error variance for the i-th Box (1/40th LFM Grid) (in mm^2/hr^2. Precise to $.1mm^2/hr^2$.

$EVsum_i$ = Sum of grid box observed ERROR VARIANCE, the sum of the observed error variance for the i-th BOX (1/40th LFM Grid) (in mm^2) and associated average TIME (Scan) for each average TIME (Scan) during the past 6 hours. Precise to $.1mm^2$.

INXmin = Minimum INDEX, computed temporary variable ranging from zero to one less than maximum Projection TIME COUNTER.

NI_i = COUNTER (Storm) for the i-th BOX (1/40th LFM grid), the number of time steps since the start of precipitation at $LOCbox_i$.

TSavg = Average TIME (Scan), mean observation time for the elevation scans used to construct the HYBRID SCAN. The observation time for any one of the scans could be used in place of the mean time if the time used differs by less than 1/1200 hours from the mean time. A precision of at least 1/1200 hours and accuracy to within 1/120 hour are required.

TB_i = BEGIN (Time), time of start of precipitation at the i-th BOX (1/40th LFM Grid) to the nearest 1/1200 hour.

TEX_i = TIME (Expired), time for the i-th BOX (1/40th LFM Grid) since last precipitation to the nearest 1/1200 hour.

TEN_i = TIME (End), ending time of precipitation at the i-th BOX (1/40th LFM Grid) to the nearest 1/1200 hour.

FIX = INTEGER (Fixed), a function that converts the real argument to an integer number by truncation.

NImax = Maximum COUNTER (Storm), the largest COUNTER (Storm) since the start of precipitation.

RSP = RATE SCAN, precipitation rate data on a 1 degree by 2 km polar grid from 1 to 230 km, in dBR. A precision of at least 0.5 dBR and a dynamic range of at least -18 to 32 dBR are required (not generated for times when FLAG (Zero Rate) or when FLAG (Bad) are set).

NS_n = NUMBER of SAMPLES, Number of Samples for COUNTER (Storm) NI.

RR_n = Total RATE (Precipitation), total RATE of precipitation for COUNTER (Storm) NI (in mm/hr). Precise to .1 mm/hr.

$RRsqr_n$ = Squared RATE (Precipitation Squared), squared total RATE of precipitation for COUNTER (Storm) NI (in mm^2/hr^2). Precise to $.1mm^2/hr^2$.

MR_n = RATE (Mean), mean (RATE) for COUNTER (STORM) NI (in mm/hr). Precise to .1mm/hr.

SD_n = RATE (Standard Deviation), the standard deviation of the rate for COUNTER (Storm) NI (in mm/hr). Precise to .1mm/hr.

$NI\ temp_i$ = Temporary COUNTER (Storm), temporary number of time steps since the start of precipitation at $LOCbox_i$.

FNP = FLAG (No Projection), a set or cleared flag for each average TIME (Scan) indicating, if set, that no projection is possible because of insufficient data or the average TIME (Scan) minus TIME (Last Precipitation Detected) is greater than TIME (Reset).

CSS = COUNTER (Storm) Sample Values, values computed for the determination of the mean precipitation of a COUNTER (Storm) and its standard deviation.

TMN = THRESHOLD (Minimum NUMBER of SAMPLES), minimum NUMBER of SAMPLES needed for a valid statistical analysis.

SDS = STORM DYNAMICS (Single COUNTER (Storm) Method), a computation that determines the mean precipitation of a COUNTER (Storm) and its standard deviation, if the THRESHOLD (Minimum NUMBER of SAMPLES) is met.

SDM = STORM DYNAMICS (Multiple COUNTER (Storm) Method), a computation that determines the mean precipitation and standard deviation of a COUNTER (Storm) , that does not meet the initial THRESHOLD (Minimum NUMBER of SAMPLES) criteria by adding samples from adjacent COUNTERs (Storm) until the THRESHOLD (Minimum NUMBER of SAMPLES) is met.

STP = STORM DYNAMICS (Projected), states that the mean and standard deviation for all COUNTERs (Storm) beyond the maximum available COUNTER (Storm) are presumed equal to the maximum available COUNTER (Storm) (simple persistence).

CCP = CORRELATION PARAMETERS, a normalization procedure which allows the residuals to be directly compared from one scan to the next to derive a single parameter residual decay.

TBX = TARGET BOX, these are the boxes searched for "upwind" of the grid box with a COUNTER (Storm) of zero. These boxes are searched for "upwind" until precipitation is detected at the TARGET BOX. The OFx, OFy and TOF from this TARGET BOX to the grid box with a COUNTER (Storm) of zero is obtained from the Storm Initiation Offset Table.

$NStemp_n$ = Temporary NUMBER OF SAMPLES, temporary number of samples for COUNTER (Storm) NI.

$RRtemp_n$ = Temporary RATE (Precipitation), temporary total RATE (Precipitation), for COUNTER (Storm) NI (in mm/hr). Precise to .1mm/hr.

$RRtempsqr_n$ = Temporary squared RATE (Precipitation), temporary squared total RATE of precipitation for COUNTER (Storm) NI (in mm^2/hr^2). Precise to $.1mm^2/hr^2$.

Δt = PROJECTION TIME STEP (hours), projection time step (hours) to the nearest 1/1200 hour.

LPR = PROJECTION INTERVAL, an even multiple of the projection time step for a given projected precipitation (in hours) to the nearest 1/1200th hour.

NIH = COUNTER (Highest Storm), highest COUNTER (Storm) NI needed for this projection.

NRT cur_i = Current RESIDUAL (Normalized), normalized RESIDUAL at the i-th BOX for the current scan.

NA = COUNTER (Autocorrelation), the number of SAMPLE VALUES available to compute autocorrelations.

L0A = LAGZERO AUTOCORRELATION, the LAGZERO AUTOCORRELATION of the normalized RESIDUALS.

L1A = LAGONE AUTOCORRELATION, the LAGONE AUTOCORRELATION of the normalized RESIDUALS.

TSavgpre = Previous average TIME (Scan), average TIME (Scan) of the previous RATE scan to the nearest 1/1200 hours.

NRT pre_i = Previous RESIDUAL (Normalized), normalized RESIDUAL at the i-th BOX for the previous scan.

PP = PROJECTION PARAMETER, a single parameter residual decay that allows the residuals to be directly compared from one scan to the next.

XI = X-COORDINATE, X-coordinate location of i-th BOX (1/40th LFM Grid). Values range from -66 to 66 with the radar located within the BOX such that XI = 0.

YI = Y-COORDINATE, Y-coordinate location of i-th BOX (1/40th LFM Grid). Values range from -66 to 66 with the radar located within the BOX such that YI = 0.

TS1
TS2
TS3
TS4
TS5
TS6
TS7
= TEMPORARY SUMs, temporary sums used in storm initiation computation.

SM1
SM2
SM3
SM4
SM5
SM7
SM8
= STORM INITIATION SUMS

SM6 = SAMPLE SIZE (Counter), sample size counter for storm INITIATION SUMs.

SID = STORM INITIATION DECAY, a decay parameter which determines the weight to be placed on previous storm motion information.

IP1
IP2 } = STORM INITIATION PARAMETERS.

D = STORM INITIATION WIDTH, the width of the rectangular region searched "upwind" for storm initiation, measured in units of grid spacing.

DYP = STORM INITIATION OFFSET LIMITS, Storm Initiation Offset Limits in the Y-direction.

OFmpy = Maximum positive Y-direction STORM INITIATION OFFSET, Maximum Storm Initiation Offset (positive Y-direction).

OFmny = Maximum negative Y-direction STORM INITIATION OFFSET, Maximum Storm Initiation Offset (negative Y-direction).

OFy = STORM INITIATION OFFSET, the Storm Initiation Offset, (Y-direction).

OFx = STORM INITIATION OFFSET, the Storm Initiation Offset (X-direction).

TOF = STORM INITIATION OFFSET TIME. Values of the Storm Initiation Offset time are integers ranging from zero to the number of time steps for which the storm projection is made. They are uniformly distributed (approximately) so that the number of entries in the Storm Initiation Offset table with any particular value of the Storm Initiation Offset time will approximately be the number of storm Initiation Offsets divided by the quantity (number of time steps of projection plus one).

PRC = Projection TIME COUNTER, the number of projection time steps in a PROJECTION INTERVAL.

VNCvarsum_n = Sum projected VARIANCE, the projected variance sum of the COUNTER (Storm) NI (in mm^2). Precise to $.1mm^2$.

VNCtemproj_i = Temporary projected VARIANCE, the temporary projected variance for the i-th BOX (1/40th LFM Grid) (in mm^2). Precise to $.1mm^2$.

NRT_itemp = Temporary RESIDUAL (Normalized), temporary normalized RESIDUAL for the i-th BOX (1/40th LFM Grid).

TSproj = Average projected TIME (Scan), average TIME (Scan) for projected RATE scan to the nearest 1/1200 hour.

SUM1 = SUM1, a computated temporary variable used to compute the terms in MULTIMATRIX.

MTXmulti = MULTIMAXTRIX, a modified correlation matrix containing the correlation of errors for each projected RATE with every other projected RATE modified for efficiency of transformation into a covariance matrix and summation of all terms in the covariance matrix.

PRCmax = Maximum PROJECTION TIME COUNTER, the maximum number of PROJECTION TIME STEPS in a PROJECTION INTERVAL.

VNCtotproj_i = Total projected VARIANCE, projected variance for the i-th BOX(1/40th LFM Grid) (in mm^2). Precise to $.1mm^2$.

PAproj_i = Projected PRECIPITATION ACCUMULATION, projected accumulation for the i-th BOX (1/40th LFM Grid) (in mm). Precise to .1mm.

RR_iproj = Projected RATE (Precipitation), projected RATE (adjusted for radar bias) of precipitation for the i-th BOX (in mm/hr). Precise to .1mm/hr.

LOCbox_i = LOCATION (box_i), refers to the BOX location within the grid.

$VNCproj_n$ = Projected VARIANCE, projected variance for COUNTER (Storm) NI (in mm^2). Precise to $.1mm^2$.

$PRtot_i$ = Total PROJECTED RATE (Precipitation), total projected RATE (Precipitation for the i-th BOX (1/40th LFM Grid) (in mm/hr). Precise to .1mm/hr.

$PAtot_i$ = Total storm PRECIPITATION ACCUMULATION, the total storm precipitation accumulation in each 1/40th LFM Grid box. The total storm precipitation refers to the sum of the total observed precipitation accumulation at the current average TIME (SCAN) and the projected precipitation (in mm). Precise to .1mm.

$VNCtot_i$ = Total VARIANCE, the total variance in the i-th BOX (1/40th LFM Grid). It is the summation of the sum grid box observed error variance at the current average TIME (SCAN) and the projected variance (in mm^2). Precise to $.1mm^2$.

LIN = LINDEX, index values that range from zero to minimum INDEX.

JIN = JINDEX, index values that range from 1 to the maximum number of projection time steps in a projection interval.

KIN = KINDEX, index values that range from JINDEX to the maximum number of projection time steps in a projection interval.

SVA = Grid box SAMPLE VALUES, values computed for the determination of the grid box observed error variance.

3.2.2 SYMBOLIC FORMULAS

COMPUTE (adjusted RATE (Precipitation))

$$RR_i adj = \left[\sum_{n=1}^{N} \frac{10^{RSP_n/10}}{N} \right] (Bcur)$$

where: sum is over N RATE SCAN sample volumes specified for a particular BOX (1/40th LFM grid).

Note: If $RSP_n \leq$ RATE (Zero Precipitation), set $RSP_n = 0.0$

COMPUTE (total observed PRECIPITATION ACCUMULATIONs)

$$PAtotobs = PAtotobs + \frac{\left[\sum_{n=1}^{N} 10^{ASSadj_n/10} \right]}{N}$$

where : sum is over N Accumulation Scans specified for a particular BOX (1/40th LFM Grid)

COMPUTE (grid box SAMPLE VALUES)

$$EVns_i = EVns_i + 1$$

$$RRevar_i = RRevar_i + RR_j adj$$

$$RRsqrevar_i = RRsqrevar_i + RR_j adj^2$$

NOTE: Subscript i refers to BOX (1/40th LFM Grid).
Subscript j refers to one of the surrounding 25 boxes (1/40th LFM Grid).

COMPUTE (grid box observed ERROR VARIANCE)

$$EV_i = \left(\frac{RRsqrevar_i}{EVns_i - 1} - \frac{(RRevar_i)^2}{EVns_i(EVns_i - 1)} \right) (EPF)$$

COMPUTE (sum of grid box observed ERROR VARIANCE)

$$EVsum_i = EVsum_i + EV_i \; (TSavg - TSavgpre)^2$$

NOTE: For the 1st scan, set TSavg - TSavgpre $= \Delta t$

COMPUTE (TIME (Expired) for this BOX)

$TEX_i = TSavg - TEN_i$

COMPUTE (COUNTER (Storm))

$$NI_i = FIX \frac{TSavg - TB_i}{\Delta t} + 1$$

COMPUTE (maximum COUNTER (Storm))

NImax = NImax or NI_i, whichever is largest.

COMPUTE (COUNTER (Storm) Sample Values)

$NS_n = NS_n + 1$

$RR_n = RR_n + RR_i adj$

$RRsqr_n = RRsqr_n + RR_i adj^2$

COMPUTE (STORM DYNAMICS (Single COUNTER (Storm) Method))

$MR_n = RR_n / NS_n$

$$SD_n = \left[\frac{RRsqr_n}{NS_n - 1} - \frac{(RR_n)^2}{NS_n (NS_n - 1)} \right]^{1/2}$$

COMPUTE (temporary COUNTER (Storm) Sample Values)

$NStemp_n = NStemp_n + NS_m$

$RRtemp_n = RRtemp_n + RR_m$

$RRtempsqr_n = RRtempsqr_n + RRsqr_m$

Note: n refers to the current COUNTER (Storm); m refers to the values of COUNTER (Storm) ranging from the current COUNTER (Storm) to NImax or ranging from the current COUNTER (Storm) -1 to 1 (stepping backwards).

COMPUTE (STORM DYNAMICS (Multiple COUNTER (Storm) Method))

$$MR_n = \frac{RRtemp_n}{NStemp_n}$$

$$SD_n = \left[\frac{RRtempsqr_n}{((NStemp_n)-1)} - \frac{(RRtemp_n)^2}{NStemp_n(NStemp_n-1)} \right]^{1/2}$$

COMPUTE (COUNTER (Highest Storm))

$$NIH = NImax + \frac{LPR}{\Delta t}$$

COMPUTE (STORM DYNAMICS (Projected))

$MR_n = MR(NImax)$

$SD_n = SD(NImax)$

Note: NI in this computation ranges from (NImax + 1) to NIH

COMPUTE (NORMALIZED RESIDUAL)

$$NRT_i cur = \frac{RR_i adj - MR_n}{SD_n}$$

Note: $NRT_i cur$ should be limited to the range -4 to 4.

COMPUTE (CORRELATION (Parameters))

$NA = NA + 1$

$L0A = L0A + (NRT_i pre) \ (NRT_i pre)$

$L1A = L1A + (NRT_i cur)(NRT_i pre)$

COMPUTE (TEMPORARY SUMS)

$TS1 = TS1 + (XI_j - XI_i)^2$

$TS2 = TS2 + (YI_j - YI_i)^2$

$TS3 = TS3 - (TB_j - TB_i)(XI_j - XI_i)$

$TS4 = TS4 - (TB_j - TB_i)(YI_j - YI_i)$

$TS5 = TS5 + (XI_j - XI_i)(YI_j - YI_i)$

$TS6 = TS6 + ABS(TB_j - TB_i)/SQRT((XI_j - XI_i)^2 + (YI_j - YI_i)^2)$

$TS7 = TS7 + 1$

Note: In the computations of the TEMPORARY SUMs the subscript i refers to the box with storm counter equal to one; the subscript j refers to a surrounding box with a storm counter greater than one.

$SM6 = SM6 + 1$

Note: SM6 is simply a sample size counter.

COMPUTE (PROJECTION PARAMETER)

IF $L1A < 0$ then set $L1A = 0$

$$PP = \left(\frac{L1A}{L0A}\right)^{\Delta t/(TSavg - TSavgpre)}$$

IF $PP > 1$, set $PP = .99$

IF $PP < 0$, set $PP = 0$

COMPUTE (STORM INITIATION SUMs)

$SM1 = TS1 + (SID)(SM1)$
$SM2 = TS2 + (SID)(SM2)$
$SM3 = TS3 + (SID)(SM3)$
$SM4 = TS4 + (SID)(SM4)$
$SM5 = TS5 + (SID)(SM5)$
$SM7 = TS6/TS7 + (SID)(SM7)$
$SM8 = 1 + (SID)(SM8)$

COMPUTE (STORM INITIATION PARAMETERs)

$$IP2 = \left[\frac{(SM3)(SM5) - (SM1)(SM4)}{(SM5)^2 - (SM1)(SM2)}\right]$$

Note: If absolute value of $IP2 < 10^{-4}$, set $IP2 = 10^{-4}$

$$IP1 = \left[\frac{SM4 - (IP2)(SM2)}{SM5}\right]$$

Note: If absolute value of $IP1 < 10^{-4}$, set $IP1 = 10^{-4}$
If the denominator of either IP1 or IP2 is zero, then set the FLAG (No Projection) and suspend processing until the next scan.

$$TEMP = \frac{SM7}{SM8(SQRT(IP1^2 + IP2^2))}$$

$IP1 = TEMP(IP1)$
$IP2 = TEMP(IP2)$

Note: The following COMPUTES assume that the absolute value of IP1   0.0001 by previous computation.

COMPUTE (STORM INITIATION OFFSET LIMITS (Y-direction))

$$DYP = ABS\left(D \frac{((IP1)^2 + (IP2)^2)^{1/2}}{2IP1} \right)$$

COMPUTE (Maximum STORM INITIATION OFFSET (positive Y-direction))

$$OFmpy = \left[FIX \quad Min(131, \frac{(IP2)(OFx)}{IP1} + DYP) \right]$$

COMPUTE (Maximum STORM INITIATION OFFSET (negative Y-direction))

$$OFmny = \left[FIX \quad Max(-131, \frac{(IP2)(OFx)}{IP1} - DYP) \right]$$

COMPUTE (STORM INITIATION OFFSET TIME)

$$TOF = \frac{(IP1)(OFx) + (IP2)(OFy)}{\Delta t}$$

SORT (STORM INITIATION OFFSET TABLE)

Note: Values of the storm Initiation Offset Time are integers ranging from zero to the number of time steps for which the storm projection is made. They are approximately uniformly distributed so that the number of entries in the Storm Initiation Offset Table with any particular value of the Storm Initiation offset Time will be approximately the Number of Storm Initiation Offsets divided by the quantity (Number of Time Steps of Projection, plus one). This may aid in the creation of a more efficient sorting routine.

COMPUTE (maximum PROJECTION TIME COUNTER)

$$PRCmax = FIX\ (\frac{LPR}{\Delta t})$$

COMPUTE (minimum INDEX)

$$INXmin = (Min(JIN,KIN) - 1)$$

COMPUTE (SUM1)

$$SUM1 = SUM1 + PP^{(KIN - JIN + 2\ (LIN))}$$

COMPUTE (MULTIMATRIX)

$$(MTXmulti)\ (JIN,\ KIN) = SUM1\ (1 - PP^{2}\ )$$

COMPUTE (Projection Times)

$$TSproj_{i} = TSavg + (i)(\Delta t)$$

NOTE: i is from 1 to PRCmax.

COMPUTE (PROJECTION TIME COUNTER)

$$PRC = \frac{TSproj_{i} - TSavg}{\Delta t}$$

COMPUTE (projected VARIANCE (sum))

$VNCvarsum_{n} = VNCvarsum_{n} + MTXmulti$
(PROJECTION TIME COUNTER, temporary PROJECTIO
TIME COUNTER • SD (COUNTER (Storm) + temporary
PROJECTION TIME COUNTER)

```
where: IF (COUNTER (Storm) + temporary PROJECTION TIME
          COUNTER < 1
          THEN SD (COUNTER (Storm) + temporary PROJECTION
                  TIME COUNTER) = 0
       IF (COUNTER (Storm) + temporary PROJECTION TIME
           COUNTER) > (NImax)
          THEN SD (COUNTER (Storm) + temporary PROJECTION
               TIME COUNTER) = SD (NImax)
```

Note: Indices (n) of VNCvarsum range from negative PRCmax to NImax.

COMPUTE (projected VARIANCE)

$$\text{VNCproj}_n = \text{SD}_m\ (\Delta t^2)\ \left(\text{VNCvarsum}_n + \frac{1}{\text{SQRT}(\text{NStemp}_m)}\right)$$

```
where: IF $m < 1$
       THEN $\text{SDm} = 0$
            $\text{NStemp}_m = 1$
       IF $m > \text{NImax}$
       THEN $\text{SDm} = \text{SD(NImax)}$
               $\text{NStemp}_m = \text{NStemp (NImax)}$
```

Note: Temporary index m = COUNTER (Storm) + PROJECTION TIME COUNTER.

COMPUTE (total Projected VARIANCE)

$$\text{VNCtotproj}_i = (\text{PRC}_{\max}\ (\text{EV}_i)\ \ \Delta t^2 + \text{VNCtempproj}_i)$$

```
where: IF (temporary COUNTER (Storm) + $\text{PRC}_{\max}) < 1$
          THEN $\text{VNCtempproj}_i = 0$
          ELSE $\text{VNCtempproj}_i = \text{VNCproj}_n\ (\text{NI}_i\text{temp})$
```

COMPUTE (projected RATE (Precipitation))

$$\text{TEMP} = (\text{PP})^{\text{PRC}}$$

$$\text{RR}_i\text{proj} = \text{MR}(\text{NI}_i\text{temp} + \text{PRC}) + \text{SD}(\text{NI}_i\text{temp} + \text{PRC})$$

$$(\text{TEMP})\ (\text{NRT}_i\text{temp})$$

Note: Value of TEMP need not be recomputed for each BOX; it varies only with PRC. If $(\text{NI}_i\text{temp} + \text{PRC})$ is less than or equal to zero, then both MR and SD are assumed zero.

COMPUTE (total PROJECTED RATE (Precipitation))

$$\text{PRtot}_i = \text{PRtot}_i + \text{RR}_i\text{proj}$$

```
COMPUTE (projected PRECIPITATION ACCUMULATION)
$PAproj_i = (PRtot_i / PRCmax)\ (LPR)$
COMPUTE (total storm PRECIPITATION ACCUMULATION)
$PAtot_i = PAtotobs_i + PAproj_i$
COMPUTE (total VARIANCE)
$VNCtot_i = EVsum_i + VNCtotproj_i$
```

.0 OUTPUTS

4.1 IDENTIFICATION

The FLAG (No Projection) is output by this algorithm.

The total observed PRECIPITATION ACCUMULATION, sum of grid box observed ERROR VARIANCE are output and the PROJECTED ACCUMULATION, total storm PRECIPITATION ACCUMULATION, and total VARIANCE are outputed unless the FLAG(No Projection) is set.

4.2 DISTRIBUTION

The FLAG (No Projection), total observed PRECIPITATION ACCUMULATION, sum of grid box observed ERROR VARIANCE, total storm PRECIPITATION ACCUMULATION, and total VARIANCE are input to the FLASH FLOOD POTENTIAL ASSESMENT [031] algorithm.

Projected PRECIPITATION ACCUMULATION and associated ERROR VARIANCE from this algorithm will be distributed to user sites and used as input to subjective and objective hydrometeorological forecast procedures for flash flood watches and warnings, river stage monitoring, and water management information applications. The projected PRECIPITATION ACCUMULATION will be used to formulate the following products:

Data Array Products:

- o The Digital projected PRECIPITATION ACCUMULATION provides, in compressed form, the projected PRECIPITATION ACCUMULATION on a 131 x 131 1/40th LFM grid.
- o The Digital Precipitation Variance provides, in compressed form, the projected and observed ERROR VARIANCE on a 131 x 131 1/40th LFM grid. Selected supplemental data would also be included and would consist most likely of storm velocity parameters, projection parameters, and storm "dynamics."

The data array products will be updated every volume scan and are intended for numerical use at computer facilities external to the NEXRAD system itself. They maintain the full dynamic range and full precision of the data used to generate the product. Data will be on a "universal" grid so that data from multiple sites are immediately compatible for rapid mosaicking and communications loadings are reduced. The grids used are supersets of the LFM grid commonly used by the NWS which is based on a polar stereographic projection.

Graphic Products:

- o The projected Precipitation Product provides the projected precipitation for up to one hour into the future on a 4 km x 4 km grid out to 230 km and will be updated every volume scan.

The graphical products are intended primarily for color graphic displays (up to 16 color levels) available at each NEXRAD PUP and are available upon request.

All of the above products, or some combination thereof, will be made available to the RFC's and to the WSFO's.

.0 INFERENCES

5.1 LIMITATIONS

The FLASH FLOOD PRECIPITATION PROJECTION algorithm does not explicitly take the following conditions into account:

1) Conditions under which precipitating areas are moving in widely varying directions at the same time.
2) Curvilinear storm motions.
3) Individual cell dynamics other than that accounted for by the current residual field.
4) Initiation of precipitation other than due to the motion of existing precipitation areas.
5) Long term mean residuals at each location in the grid.

5.2 FUTURE DEVELOPMENTS

Adaptation parameter values will be "fine tuned" using actual NEXRAD data.

FLASH FLOOD POTENTIAL ASSESSMENT

ALGORITHM DESCRIPTION

NX-DR-03-031/03

1.0 PROLOGUE

1.1 FUNCTIONAL DESCRIPTION

THE FLASH FLOOD POTENTIAL ASSESSMENT algorithm uses flash flood guidance values developed by the River Forecast Centers (RFCs), and observed and projected precipitation accumulations output from the FLASH FLOOD PRECIPITATION PROJECTION algorithm to produce observed and projected flash flood probabilities. These flash flood guidance values are based on pre-runs of the hydrologic models by the RFCs. They determine how much rainfall would be required over specified durations (up to three different durations with the maximum duration being limited to six hours) to produce flooding, given the current hydrologic conditions, at one or more locations within a zone or county. The flash flood guidance values are then compared to the observed and the total storm (projected plus observed) precipitation accumulations for that particular flash flood guidance value duration, and an observed and projected probability of flash flooding is computed for each 1/40th LFM grid box. This algorithm also computes the zonal maximum observed precipitation accumulation, the zonal maximum total storm (projected plus observed) precipitation accumulation for each guidance value duration in each flash flood guidance zone, and the zonal maximum observed and projected flash flood probability among all guidance values for each zone.

1.2 SOURCE

THE FLASH FLOOD PROBABILITY ASSESSMENT algorithm was developed by the Radar Hydrology Group of the National Weather Service's Hydrologic Research Laboratory. This algorithm has been based on experiences gained through the use of real-time rainfall estimation from the D/RADEX system, the GATE project, and other experimental projects as well as an in-depth analysis of ways with which weather radar data could be better used for hydrometerological purposes.

1.3 PROCESSING ENVIRONMENT

This algorithm requires output from the FLASH FLOOD PRECIPITATION PROJECTION algorithm and flash flood guidance values acquired from the River Forecast Centers (RFCs) using the existing rain gage data acquisition port on the Radar Product Generator (RPG).

The algorithm must keep track of many variables over an entire precipitation event. Loss of any information during this time will seriously damage its operation. Therefore, the methods used to save these variables must be safe from temporary system shutdowns and restarts.

The Limited Fine Mesh (LFM) grid is a rectangular grid commonly used by the National Weather Service which is based on a polar stereographic projection. An LFM grid box represents an area whose size and shape varies with latitude. Therefore the size and shape of the grid boxes will vary slightly over the area covered by the radar and even more from radar to radar. The orientation and mesh length of the LFM grid is designed to contain the NWS Manually Digitized Radar (MDR) and the National Weather Service River Forecast System (NWSRFS)/Hydrologic Rainfall Analysis Project (HRAP) grids as subsets. The MDR grid mesh length is 1/4th the length of the LFM grid mesh. The NWSRFS/HRAP grid mesh length is 1/40th and 1/10th the lengths of the LFM and MDR grid mesh, respectively. As a result, the MDR grid is commonly referred to as the 1/4th LFM Grid and the NWSRFS/HRAP grid is often called the 1/40th LFM Grid. The grid mesh lengths of the LFM, 1/4th LFM and 1/40th LFM at 60°N latitude are 190.5 km, 47.625 km and 4.7625 km, respectively. The information required to generate the grid for each site are the latitude and longitude of the radar, and the mesh length at 60°N (the standard latitude) and 105°W (the standard longitude). In order to cover the radar umbrella out to 230 km, especially in the lower latitudes of the conterminous U.S., a 131 by 131 array of 1/40th LFM grid boxes will be required. This array will always be 131 by 131 regardless of the site latitude. The grid should be positioned in such a way that the radar site falls within the grid box (66,66).

Generally rainfall rates or accumulations can be retained in two types of units. The more familiar linear units are in mm (for accumulations) or mm/hr (for rates). Logarithmic units can also be used (dBA for accumulations, dBR for rates). The storage requirements for the logarithmic units are approximately one-half that for linear units (about 8 bits/value as opposed to 16 bits/value). However, several computations must be done in linear units which necessitates conversions from logarithmic to linear units (and vice versa) if logarithmic units are used. Since these conversions incur a penalty on CPU time, this algorithm is written in linear units.

Wherever a power of 10 or base 10 logarithm is found in these algorithms, a conversion from logarithmic units to linear units or vice versa is taking place. This conversion can be done by actually computing the powers and logarithms at each sample volume or through the use of a computation saving technique such as the use of a discrete conversion table or any other technique providing sufficient precision.

The units used for external communications should be chosen on the basis of communications requirements regardless of the units used for internal computations.

.0 INPUTS

2.1 IDENTIFICATION

FLAG(No Projection) = A set or cleared flag for each average TIME (Scan) indicating, if set, that no projection is possible because of insufficient data or the average TIME (Scan) minus TIME (Last Precipitation Detected) is greater than TIME (Reset).

total observed PRECIPITATION ACCUMULATION = Total observed precipitation accumulation (adjusted for the estimated mean field bias) for the i-th BOX (1/40th LFM Grid) (in mm) and associated average TIME (Scan) for each average TIME (Scan) during the past 6 hours.

sum of grid box observed ERROR VARIANCE = The sum of the grid box observed error variance for the i-th BOX (1/40th LFM Grid) (in mm^2) and associated average TIME (Scan) for each average TIME (Scan) during the past 6 hours.

total storm PRECIPITATION ACCUMULATION = The total storm precipitation accumulation in each 1/40th LFM Grid box. The total storm precipitation accumulation refers to the sum of the total observed precipitation accumulation at the current average TIME (Scan) plus the projected precipitation (in mm).

FLASH FLOOD (Guidance Table) = A table composed of three columns:
(1) FLASH FLOOD (Zone)
(2) FLASH FLOOD (Guidance Value)
(3) FLASH FLOOD (Guidance Duration)
Each entry in the table gives a rainfall accumulation in mm (the Guidance Value) which will cause flash flooding within a particular geographic area (the Zone) if it occurs over a particular duration in hours (the (Guidance Duration). The FLASH FLOOD (Guidance Table) is produced at the River Forecast Centers (currently once a day) and communicated to the RPG using the existing rain gage data acquisition port.

total VARIANCE = The total variance in each i-th Box (1/40th LFM Grid). It is the summation of the sum of grid box observed error variance at the current average TIME (Scan) and the projected variance. (in mm^2).

2.2 ACQUISITION

FLAG (No Projection), total observed PRECIPITATION ACCUMULATION, sum of grid box observed ERROR VARIANCE, total storm PRECIPITATION ACCUMULATION, and total VARIANCE are obtained from the FLASH FLOOD PRECIPITATION PROJECTION [30] algorithm.

FLASH FLOOD guidance values are obtained from the River Forecast Centers via the raingage data acquisition port.

3.0 PROCEDURE

3.1 ALGORITHM

```
BEGIN ALGORITHM (FLASH FLOOD POTENTIAL ASSESSMENT)

1.0  DO FOR ALL (FLASH FLOOD (ZONES))

          Set zonal maximum observed PRECIPITATION ACCUMULATION
              for all FLASH FLOOD (Guidance Durations) to zero
              for this FLASH FLOOD (Zone).
          Set zonal maximum observed FLASH FLOOD PROBABILITY for
              all FLASH FLOOD (Guidance Durations) to zero for
              this FLASH FLOOD (Zone).
          Set zonal maximum total storm PRECIPITATION ACCUMULA-
              TION for all FLASH FLOOD (Guidance Durations) to
              zero for this FLASH FLOOD (Zone)
          Set zonal maximum total storm FLASH FLOOD PROBABILITY
              for all FLASH FLOOD (Guidance Durations) to zero
              for this FLASH FLOOD (Zone)

     1.1   DO FOR ALL (BOX (1/40th LFM Grid) within FLASH FLOOD
                      (Zone))

                Set maximum observed FLASH FLOOD PROBABILITY to
                    zero
                Set maximum projected FLASH FLOOD PROBABILITY to
                    zero

          1.1.1   DO FOR ALL  FLASH FLOOD (Guidance Values) for
                              this zone

                              COMPUTE (observed PRECIPITATION
                                      ACCUMULATION for Guidance
                                      Duration)
                              COMPUTE (zonal maximum observed
                                      PRECIPITATION ACCUMULATION
                                      for Guidance Duration)
                              COMPUTE (OBSERVED ERROR VARIANCE for
                                      Guidance Duration)
                              COMPUTE (observed FLASH FLOOD PROBABIL-
                                      ITY)
                              COMPUTE (maximum observed FLASH FLOOD
                                      PROBABILITY)
                              IF FLAG (No Projection) clear
                              THEN
                                  COMPUTE (total storm PRECIPITATION
                                          ACCUMULATION for Guidance
                                          Duration)
                                  COMPUTE (zonal maximum total storm
                                          PRECIPITATION ACCUMULATION
                                          for Guidance Duration)
                    COMPUTE (total VARIANCE for Guidance Duration)
                    COMPUTE (projected FLASH FLOOD PROBABILITY)
                    COMPUTE (maximum projected FLASH FLOOD PROBABILITY)
                END IF
            END DO
            COMPUTE (zonal maximum observed FLASH FLOOD PROBABILITY)
            WRITE (maximum observed FLASH FLOOD PROBABILITY
            IF FLAG (No Projection) clear
            THEN
                COMPUTE (zonal maximum total storm FLASH FLOOD PROBABILITY)
            WRITE (maximum projected FLASH FLOOD PROBABILITY)
            END IF
      END DO
      WRITE (zonal maximum observed PRECIPITATION ACCUMULATION for all Guidance Durations)
      WRITE (zonal maximum observed FLASH FLOOD PROBABILITY)
            IF FLAG (No Projection) clear
            THEN
            WRITE (maximum total storm PRECIPITATION ACCUMULATION for all Guidance Durations)
            WRITE (zonal maximum total storm FLASH FLOOD PROBABILITY)
            END IF
END DO
END ALGORITHM (FLASH FLOOD POTENTIAL ASSESSMENT)
```

3.2 COMPUTATION

3.2.1 NOTATION

PAobs_i = Observed PRECIPITATION ACCUMULATION, observed precipitation accumulation for the i-th BOX (1/40th LFM Grid) for a particular Guidance Duration (in mm). Precise to .1mm.

PAzonmaxobs_j = Zonal maximum observed PRECIPITATION ACCUMULATION, the maximum observed precipitation accumulation for a particular Guidance Duration for the j-th Flash Flood Guidance Zone (in mm). Precise to .1mm.

OEV_i = OBSERVED ERROR VARIANCE, the observed error variance for the i-th BOX (1/40th LFM Grid) for a particular Guidance Duration (in mm^2). Precise to $.1\text{mm}^2$.

FFPobs_i = Observed FLASH FLOOD PROBABILITY, the observed flash flood probability for the i-th BOX (1/40th LFM Grid) for a particular Guidance Duration (in percent). Precise to .02 percent.

FFPmaxobs_i = Maximum observed FLASH FLOOD PROBABILITY, the maximum observed flash flood probability for all Guidance Durations for the i-th BOX (1/40th LFM Grid) (in percent). Precise to .02 percent.

FFPzonmaxobs_j = Zonal maximum observed FLASH FLOOD PROBABILITY, the maximum observed flash flood probability among all Guidance Durations and all Boxes (1/40th LFM Grid) in the j-th Zone (in percent). Precise to .02 percent.

PAtotaccum_i = Total storm (Guidance Duration) PRECIPITATION ACCUMULATION, the total storm precipitation accumulation for i-th BOX (1/40th LFM Grid) for a particular Guidance Duration (in mm). Includes the projected accumulations for the entire project period plus observed accumulations. Precise to .1mm.

FFGV = FLASH FLOOD (Guidance Value), the flash flood Guidance Value is the amount of rainfall over a specified duration required to produce flooding (in inches). Precise to 0.1 inch.

FFPmaxproj_i = Maximum projected FLASH FLOOD PROBABILITY, the maximum projected flash flood probability of a particular Guidance Duration for the i-th BOX (1/40th LFM Grid) (in percent). Precise to .02 percent.

PAtotobs_i = Total observed PRECIPITATION ACCUMULATION, total observed precipitation accumulation (adjusted for the estimated mean field bias) for the i-th BOX (1/40th LFM Grid) (in mm) and associated average TIME (Scan) for each average TIME (Scan) during the past 6 hours. Precise to .1mm.

PAmaxtotaccum_j = Zonal maximum total storm (Guidance Duration) PRECIPITATION ACCUMULATION, the maximum total storm precipitation accumulation for a particular Guidance Duration for the j-th Flash Flood Guidance Zone (in mm). Precise to .1mm.

VNCtotgvd_i = Total guidance value VARIANCE, the total variance for the i-th BOX (1/40th LFM Grid) for a particular Guidance Duration (in mm^2). Precise to $.1\text{mm}^2$.

FFPproj = Projected FLASH FLOOD PROBABILITY, the projected flash flood probability for the i-th BOX (1/40th LFM Grid) for a particular Guidance Duration (in percent). Precise to .02 percent.

EVsum_i = Sum of grid box observed ERROR VARIANCE, the sum of the grid box observed error variance for the i-th BOX (1/40th LFM Grid) (in mm^2) and associated average TIME (Scan), for each average TIME (Scan) during the past 6 hours. Precise to $.1\text{mm}^2$.

$PAtot_i$ = Total storm PRECIPITATION ACCUMULATION, the total storm precipitation accumulation in each 1/40th LFM Grid box. The total storm precipitation accumulation refers to the sum of the total observed precipitation accumulation at the current average TIME(Scan) and the projected precipitation. (in mm). Precise to .1mm.

$VNCtot_i$ = Total VARIANCE, the total variance in each i-th BOX (1/40th LFM Grid). It is the summation of the sum of grid box observed error variance at the current average TIME (Scan) and the projected variance (in mm^2). Precise to $.1mm^2$.

$FFPzonmaxproj_j$ = Zonal maximum total storm FLASH FLOOD PROBABILITY, the maximum total storm flash flood probability among all Guidance Durations and all BOXes (1/40th LFM Grid) in the j-th Zone. (in percent). Precise to .02 percent.

3.2.2 SYMBOLIC FORMULAS

COMPUTE (observed PRECIPITATION ACCUMULATION for Guidance Duration)

$PAobs_i = PAtotobs_i$(present scan) − $PAtotobs_i$(of the scan with an Average TIME (Scan) nearest in time to a Guidance Duration ago)

Note: Early in a precipitation event, the scan with the Average TIME(Scan) nearest in time to a Guidance Duration ago will commonly be the first scan with non-zero precipitation in the event.

COMPUTE (zonal maximum observed PRECIPITATION ACCUMULATION for Guidance Duration)

$PAzonmaxobs_j = [\max (PAobs_i, PAzonmaxobs_j)]$

Note: In the computation of the maximum observed PRECIPITATION ACCUMULATION for Guidance Duration; the subscript i refers to the BOX (1/40th LFM Grid) and the subscript j refers to the FLASH FLOOD Guidance Zone.

COMPUTE (OBSERVED ERROR VARIANCE for Guidance Duration)

$OEV_i = EVsum_i$(present scan) - $EVsum_i$(of the scan with an average TIME (Scan) nearest in time to a Guidance Duration ago)

Note: Early in a precipitation event, the scan with the Average TIME(Scan) nearest in time to a Guidance Duration ago will commonly be the first scan with non-zero precipitation in the event.

COMPUTE (observed FLASH FLOOD PROBABILITY)

Note: The observed FLASH FLOOD PROBABILITY, ($FFPobs_i$) is the probability that a random variable sampled from a normal probability distribution with mean equal to PAobs and variance equal to OEV will exceed the guidance value. This probability can be computed by creation of standardized normal deviate "Y" of the form:

$$Y = \left[\frac{PAobs_i - FFGV}{(OEV_i)^{1/2}} \right]$$

The observed FLASH FLOOD PROBABILITY is then the probability that a normal random variable from a zero mean, unit variance population exceeds the value "Y".

This probability can be computed from any number of standard mathematical subroutine libraries (see for example subroutine MDNOR in the IMSL library). This probability need only be accurate to ± 0.02, therefore a table lookup approach can also be employed to improve computational efficiency.

Note: If the denominator of the computation of "Y" is less than or equal to zero, set the denominator to 0.001.

COMPUTE (maximum observed FLASH FLOOD PROBABILITY)

$FFPmaxobs_i = [\max (FFPobs_i, FFPmaxobs_i)]$

COMPUTE (total storm PRECIPITATION ACCUMULATION for Guidance Duration)

$PAtotaccum_i = PAtot_i$ (maximum Projected time) - $PAtotobs_i$ (of the scan with an average TIME (Scan) nearest in time to a Guidance Duration before the end of the Projection Interval).

Note: Early in a precipitation event, the scan with the Average TIME(Scan) nearest in time to a Guidance Duration before the end of the project interval will commonly be the first scan with non-zero precipitation in the event.

COMPUTE (zonal maximum total storm PRECIPITATION ACCUMULATION for Guidance Duration)

$$\text{PAmaxtotaccum}_i = [\max(\text{PAtotaccum}_i, \text{PAmaxtotaccum}_j)]$$

Note: In the computation of the zonal maximum total storm PRECIPITATION ACCUMULATION for Guidance Duration, the subscript i refers to the BOX (1/40th LFM Grid) and the subscript j refers to FLASH FLOOD Guidance Zone.

COMPUTE (total VARIANCE for Guidance Duration)

$\text{VNCtotgvd}_i = \text{VNCtot}_i$ (Maximum Projected Time) - EVsum_i (of the scan with average TIME (Scan) nearest in time to a Guidance Duration before the end of the PROJECTION INTERVAL).

Note: Early in a precipitation event, the scan with the Average TIME(Scan) nearest in time to a Guidance Duration before the end of the projection interval will commonly be the first scan with non-zero precipitation in the event.

COMPUTE (projected FLASH FLOOD PROBABILITY)

Note: This computation follows the same procedure as the observed FLASH FLOOD PROBABILITY, but with "Y" defined by:

$$Y = \left[\frac{\text{PAtotaccum}_i - \text{FFGV}}{(\text{VNCtotgvd}_i)^{1/2}} \right]$$

Y is then used to compute the projected FLASH FLOOD PROBABILITY (FFPproj_i)

Note: If the denomenator of the computation of "Y" is less than or equal to zero, set the denominator to 0.001.

```
COMPUTE (zonal maximum observed FLASH FLOOD PROBABILITY)
$FFPzonmaxobs_j = Max(FFPzonmaxobs_j, FFPmaxobs_i)$
COMPUTE (zonal maximum total storm FLASH FLOOD PROBABILITY)
$FFPzonmaxproj_j = Max(FFPzonmaxproj_j, FFPmaxproj_i)$
COMPUTE (maximum projected FLASH FLOOD PROBABILITY)
$FFPmaxproj_i = [max (FFPproj_i, FFPmaxproj_i)]$
```

0 OUTPUTS

4.1 IDENTIFICATION

The following are output by this algorithm: maximum observed FLASH FLOOD PROBABILITY and maximum projected FLASH FLOOD PROBABILITY (maximum of the Guidance Durations) at each BOX (1/40th LFM Grid); and the zonal maximum observed PRECIPITATION ACCUMULATION, zonal maximum total storm PRECIPITATION ACCUMULATION, zonal maximum observed FLASH FLOOD PROBABILITY, and zonal maximum total storm FLASH FLOOD PROBABILITY (maximum among all Guidance Durations for each FLASH FLOOD (Guidance Zone)).

Note that the maximum projected FLASH FLOOD PROBABILITY, zonal maximum total storm FLASH FLOOD PROBABILITY, and zonal maximum total storm PRECIPITATION ACCUMULATION are output only when the FLAG (No Projection) is clear.

4.2 DISTRIBUTION

Products generated from the above outputs will be distributed to user sites and used as input to subjective and objective hydrometeorological forecast procedures for flash flood watches and warnings, river stage monitoring, and water management information applications. These outputs will be used to generate the following products:

Graphical Products:

- The maximum observed FLASH FLOOD PROBABILITY Product provides, on a 4 km x 4 km grid out to 230 km, the maximum observed FLASH FLOOD PROBABILITY and will be updated every volume scan.
- The maximum projected FLASH FLOOD PROBABILITY Product provides, on a 4 km x 4 km grid out to 230 km, the maximum projected FLASH FLOOD PROBABILITY and be updated every volume scan.

The graphic products are intended primarily for color graphic displays (up to 16 color levels) available at each NEXRAD PUP and are available upon request.

Alphanumeric Products:

- The FLASH FLOOD Guidance Summary Product will be updated every volume scan and provides, in an alphanumeric table: the guidance value, zonal maximum observed PRECIPITATION ACCUMULATION, and zonal maximum total storm (observed and projected) PRECIPITATION ACCUMULATION for each guidance value duration in each FLASH FLOOD guidance zone.

- The zonal maximum FLASH FLOOD PROBABILITY Product will be updated every scan and provides, in an alphanumeric format, the zonal maximum observed and projected FLASH FLOOD PROBABILITIES.

The alphanumeric products provide FLASH FLOOD PROBABILITY information in a form suitable for display on both graphic and alphanumeric display devices.

All of the above products, or some combination thereof, will be made available to the RFC's and to the WSFO's. The above products should be viewed by the forecasters as very useful guidance, but not as definitive identification of flash flooding until interpreted together with other information at their disposal.

5.0 INFERENCES

5.1 LIMITATIONS

Flash Flood guidance problems:

a) Data base may not allow models to accurately reflect soil moisture.

b) Multiple rainfall events cause problems--need updating procedure.

c) Flash Flood guidance does not reflect criteria for urban areas.

d) RFC discontinuities--not all River Forecast Centers calculate flash flood guidance values the same way.

e) Flash flood guidance produced by servicing River Forecast Centers usually only once a day.

5.2 FUTURE DEVELOPMENTS

Adaptation parameter values will be "fine tuned" using actual NEXRAD data.

COMBINED SHEAR

ALGORITHM DESCRIPTION

NX-DR-03-033/03

MAJOR REVISIONS SINCE MAY 1984

Combined Shear (033)

1. All algorithms appearing in the May 1984 report have undergone the following changes:

   a. Editorial and typographical changes.

   b. Explicit declaration of data element precision.

   c. Renaming of data element names and symbols to achieve unique naming.

   d. Data Dictionary changes resulting from other changes.

2. Several fundamental changes have been made to the Shear Algorithm (010). First the name has been changed to Combined Shear (033) due to the combining of the radial and tangential shears (This was accomplished by taking their root sum squares.) In addition to this, gridding has been introduced to eliminate range biases and to achieve the degree of filtering needed for successful product generation. Finally, the product concept has been changed. Rather than permitting numerous independent product requests, the algorithm produces one 230x230 km product from which users may extract windows.

.0 PROLOGUE

1.1 FUNCTIONAL DESCRIPTION

This algorithm computes combined shear of the radial velocities at a single elevation within a volume scan. This combined shear is related but not equivalent to the total shear of the horizontal wind field. Since most wind phenomena related to aircraft mishaps involve shears (gradients of the wind), maps of the combined shear of the radial velocities as measured by Doppler weather radar will prove useful in the detection of such hazards.

On an azimuth-by-azimuth basis the algorithm performs the following calculations:

1) Running averages of Doppler velocity over a specified number of sample volumes. Only those data values with corresponding received power levels greater than a specified threshold power are included in the averages.

2) Running differences of the radially-averaged Doppler velocities. These differences are taken over a radial distance equal to the averaging distance. For final processing, the differences are assigned to Cartesian grid points.

3) Azimuthal differences of the radially-averaged Doppler velocities. These differences are taken between adjacent azimuths at constant range. For final processing, the differences are divided by the distance between the effective sample volume centers, with the quotients then assigned to Cartesian grid points.

Once all azimuths have been processed, the following are computed within the rectangular Cartesian grid:

1) Average radial and azimuthal differences at each grid point.

2) Filtered difference fields using a centered, two-dimensional filter.

3) Combined shear of the radial velocities at each grid point by squaring the radial and azimuthal shears, adding, and taking the square root.

4) Thresholded total shears, where only those values above a defined threshold are retained.

This process yields a field of shear values that are easily displayed and are available as input to higher level algorithms, such as a GUST FRONT DETECTION algorithm.

1.2 SOURCE

The algorithm was developed at the Air Force Geophysics Laboratory (LYR) by F. Ian Harris (SASC Technologies, Inc.), Kenneth M. Glover (AFGL/LYR) and Glenn R. Smythe (SASC Technologies, Inc.).

REFERENCE

Harris, F.I., K.M. Glover and G.R. Smythe, 1985: Gust Front Detection and Prediction. Preprints 14th Conference on Severe Local Storms, Amer. Meteor. Soc., Boston, MA.

1.3 PROCESSING ENVIRONMENT

This algorithm uses reflective power and dealiased radial velocity data collected by a Doppler weather radar. Ground clutter effects are assumed to have been removed. The data are treated on a plane basis only, i.e., no vertical correlations are performed.

0 INPUTS

2.1 IDENTIFICATION

AZIMUTH = Azimuthal position, in radians.

DOMAIN(Resolution) = Grid point spacing for the Cartesian grid, in km (0.5 - 4.0).

DOMAIN(X Minimum) = The lower left X (W - E) coordinate relative to the radar for the rectangular Cartesian grid for the interpolated shears, in km.

DOMAIN(Y Minimum) = The lower left Y (S - N) coordinate relative to the radar for the rectangular Cartesian grid for the interpolated shears, in km.

DOMAIN(X Size) = Length of the (W - E) side of the Cartesian grid box, in km (230). Note: The box is centered on the radar.

DOMAIN(Y Size) = Length of the (S - N) side of the Cartesian grid box, in km (230). Note: The box is centered on the radar.

ELEVATION = Elevation angle, in radians.

FLAG VALUE = Default value for filtered SHEAR (Radial-RSA), filtered SHEAR(Azimuthal) and COMBINED SHEAR.

MAXIMUM SAMPLES (Radial) = The maximum number of SAMPLE VOLUMEs in one radial.

NUMBER(Filter) = Number of data points used in the uniform filter applied to the mean SHEAR(Azimuthal) and mean SHEAR (Radial) fields (9).

NUMBER (Sample Volumes) = Number of contiguous SAMPLE VOLUMEs to be averaged to produce each estimate of average RADIAL VELOCITY (Range)(3). Also used in determining the difference distance for the radial shear computations.

POWER = Received power for each SAMPLE VOLUME, in dBm.

RANGE (Slant) = The slant range to the center of a SAMPLE VOLUME, in kilometers.

Azimuth RANGE SAMPLE SPACING = Differences in range between two adjacent SAMPLE VOLUMEs along an azimuth.

THRESHOLD (Number) = The minimum fraction of NUMBER (Radial Difference) to NUMBER (Potential Difference Radial) and of NUMBER (Azimuthal Difference) to NUMBER (Potential Difference Azimuthal) for the calculations of the respective shears (.75).

THRESHOLD (Combined Shear) = The minimum combined shear value allowed for acceptance in the final shear field, in 1/hr (8-16).

THRESHOLD (Velocity Power) = The received power above which velocities will be processed, in dB (5-10).

VELOCITY (Doppler) = Doppler velocities in a SAMPLE VOLUME, in km/hr.

2.2 ACQUISITION

AZIMUTH, ELEVATION, RANGE(Slant) and RANGE SAMPLE SPACING are obtained by direct measurement.

VELOCITY (Doppler) and POWER are obtained directly from the basic data acquisition process of the Doppler radar system.

DOMAIN(Resolution), DOMAIN(X Minimum), DOMAIN(Y Minimum), DOMAIN(X Size), DOMAIN(Y Size), FLAG VALUE, NUMBER(Filter), MAXIMUM SAMPLES(Radial), NUMBER(Sample Volumes), Threshold (Number), THRESHOLD(Velocity Power), and THRESHOLD (Combined Shear) are all input parameters and are all site-adaptable.

3.0 PROCEDURE

3.1 ALGORITHM

```
BEGIN ALGORITHM (COMBINED SHEAR)

1.0 COMPUTE (AZIMUTH LIMITS)
2.0 COMPUTE (RANGE LIMITS)
3.0 COMPUTE (X-DIMENSION)
4.0 COMPUTE (Y-DIMENSION)

5.0 DO (AZIMUTHs) FROM minimum AZIMUTH TO maximum AZIMUTH
    5.1 DO (RANGEs(Slant)) FROM minimum RANGE(Slant) TO maximum
        RANGE(Slant)
        5.1.1 COMPUTE (average VELOCITYs(Doppler))
        END DO
    5.2 DO (RANGEs(Slant)) FROM minimum RANGE(Slant) TO maximum
        RANGE(Slant)
        5.2.1 COMPUTE (DIFFERENCE(Radial))
        5.2.2 COMPUTE (radial X-INDEX)
        5.2.3 COMPUTE (radial Y-INDEX)
        5.2.4 IF ((radial X-INDEX) is not less than zero AND
              (radial X-INDEX) is not greater than (X-DIMENSION)
              AND (radial Y-INDEX) is not less than zero
              AND (radial Y-INDEX) is not greater than (Y-DIMEN-
                  SION))
              THEN
                   COMPUTE (NUMBER(Potential Difference Radial))
                   COMPUTE (SUM(Radial Difference))
                   COMPUTE (NUMBER(Radial Difference))
              END IF
        5.2.5 IF (Current AZIMUTH is not first processed
                 azimuth)
              THEN
                 COMPUTE (DIFFERENCE(Azimuthal))
                 COMPUTE (azimuthal X-INDEX)
                 COMPUTE (azimuthal Y-INDEX)
                 IF ((azimuthal X-INDEX) is not less than
                    zero AND (azimuthal X-INDEX) is not
                    greater than (X-DIMENSION) AND (azimuthal
                    Y-INDEX) is not less than zero AND
                    (azimuthal Y-INDEX) is not greater than
                    (Y-DIMENSION))
                 THEN
                    COMPUTE (NUMBER(Potential Difference
                                    Azimuthal))
                    COMPUTE (SUM(Azimuthal Difference))
                    COMPUTE (NUMBER(Azimuthal Difference))
                 END IF
              END IF
        END DO
    END DO
```

```
6.0 DO FOR ALL (SUM(Radial Difference) and SUM(Azimuthal
                Difference))
    6.1 IF (NUMBER(Radial Difference) is greater than (THRESHOLD
        (Number) x Number(Potential Difference Radial)) and NUMBER
        (Azimuthal Difference) is greater than (THRESHOLD(Number)
        x NUMBER(Potential Difference Azimuthal)))
        THEN
        6.1.1 COMPUTE (mean SHEAR(Radial-RSA))
        6.1.2 COMPUTE (mean SHEAR(Azimuthal))
        ELSE
        SET (mean SHEAR(Radial-RSA)) to FLAG VALUE
        SET (mean SHEAR (Azimuthal)) to FLAG VALUE
        END IF
    END DO
```

NOTE: The FLAG VALUE should be some value not in the range of possible shear values, i.e., the flag value should NOT be equal to zero.

```
7.0 DO FOR ALL (mean SHEAR(Radial-RSA) and mean SHEAR(Azimuthal))
     7.1 COMPUTE (filtered SHEAR(Radial-RSA))
     7.2 COMPUTE (filtered SHEAR(Azimuthal))
     7.3 COMPUTE (COMBINED SHEAR)
         7.3.1 IF (COMBINED SHEAR is less than THRESHOLD(Combined
                   Shear))
               THEN
               Set COMBINED SHEAR to 0
               END IF
    END DO

8.0 WRITE (COMBINED SHEAR)

END ALGORITHM (COMBINED SHEAR)
```

3.2 COMPUTATION

3.2.1 NOTATION

AZ = AZIMUTH, azimuthal position, in radians. Precise to 10^{-2} radians.

AZmin = minimum AZIMUTH, minimum azimuth angle to be processed. Value determined by the Cartesian grid specification, in radians. Precise to 10^{-2} radians.

AZmax = maximum AZIMUTH, maximum azimuth angle to be processed. Value determined by the Cartesian grid specification, in radians. Precise to 10^{-2} radians.

AZA1,AZA2, AZA3,AZA4 = AZIMUTH LIMITS, azimuth angles to the vertices of the Cartesian grid, with the radar as the origin.

CFLA = COUNT FILTER (Azimuthal), count of the number of (mean SHEAR (Azimuthal)) values used in filter for current point being filtered. This value will always be less than or equal to NUMBER(Filter).

CFLR = COUNT FILTER (Radial), count of the number of (mean SHEAR (Radial)) values used in filter for current point being filtered. This value will always be less than or equal to NUMBER(Filter).

DA = DIFFERENCE(Azimuthal), differences in average VELOCITY (Doppler) computed between adjacent azimuths and at constant range.

DOR = DOMAIN(Resolution), grid point spacing for the Cartesian grid, in km (0.5 - 4.0).

DR = DIFFERENCE(Radial), radial differences in average VELOCITY(Doppler) computed between sample volumes spaced NUMBER(Sample Volumes) apart and at constant azimuth.

DXM = DOMAIN(X Minimum), the lower left X (W - E) coordinate relative to the radar for the rectangular Cartesian grid for the interpolated shears, in km.

DXS = DOMAIN(X Size), length of the (W - E) side of the Cartesian grid box, in km (230). Note: The box is centered on the radar.

DYM = DOMAIN(Y Minimum), the lower left Y (S - N) coordinate relative to the radar for the rectangular Cartesian grid for the interpolated shears, in km.

DYS = DOMAIN(Y Size), length of the (S - N) side of the Cartesian grid box, in km (230). Note: The box is centered on the radar.

FLV = FLAG VALUE, default value for filtered SHEAR (Radial-RSA), filtered SHEAR(Azimuthal) and COMBINED SHEAR.

MSR = MAXIMUM SAMPLES(Radial), the maximum number of SAMPLE VOLUMEs in one radial.

NAD = NUMBER(Azimuthal Difference), number of azimuthal shear values accumulated at each grid point.

NFL = NUMBER(Filter), number of data points used in the uniform filter applied to the mean SHEAR (Azimuthal) and mean SHEAR(Radial) fields (9).

NGR = NUMBER(Good Radial Velocities), number of good radial velocity values which have gone into the corresponding average VELOCITY(Doppler) computation.

NPDR = NUMBER(Potential Difference Radial), total number of DIFFERENCE(Radial) values that could potentially contribute to the COMBINED SHEAR at each grid point if all acceptance criteria are met.

NPDA = NUMBER(Potential Difference Azimuthal), total number of DIFFERENCE(Azimuthal) values that could potentially contribute to the COMBINED SHEAR at each grid point if all acceptance criteria are met.

NRD = NUMBER(Radial Difference), number of radial shear values accumulated at each grid point.

NSV = NUMBER(Sample Volumes), number of contiguous SAMPLE VOLUMEs to be averaged to produce each estimate of average VELOCITY(Doppler) (3). Also used in determining the difference distance for the radial shear computations.

NTH = THRESHOLD(Number), the minimum fraction of NUMBER(Radial Difference) to NUMBER(Potential Difference Radial) and of NUMBER(Azimuthal Difference) to NUMBER(Potential Difference Azimuthal) for the calculations of the respective shears (.75).

PHI# = ELEVATION, elevation angle, in radians. Precise to 10^{-2} radians.

POW = POWER, received power for each SAMPLE VOLUME, in dBm.

RSmax = maximum RANGE(Slant), maximum range for which the data are to be processed. Value determined by the Cartesian grid specification, in kilometers. Precise to 10^{-2} kilometers.

RSmin = minimum RANGE(Slant), minimum range for which the data are to be processed. Value determined by the Cartesian grid specification, in kilometers. Precise to 10^{-2} kilometers.

RS = RANGE(Slant), the slant range to the center of a SAMPLE VOLUME, in kilometers. Precise to 10^{-2} kilometers.

RSSazi = Azimuth RANGE SAMPLE SPACING, differences in range between two adjacent SAMPLE VOLUMEs along an azimuth, in kilometers. Precise to 10^{-2} kilometers.

VD = VELOCITY(Doppler), Doppler velocities in a SAMPLE VOLUME, in km/hr.

VDavg = average VELOCITY(Doppler), running average in range of radial velocity. in km/hr.

R1,R2,R3,R4 = RANGE LIMITS, ranges from the radar to the vertices of the Cartesian grid.

SAD = SUM(Azimuthal Difference), sum of the azimuthal differences at each Cartesian grid point.

SAfilter = filtered SHEAR(Azimuthal), shear values derived by imposing an uniform filter to the field of mean SHEAR(Azimuthal) values.

SAmean = mean SHEAR(Azimuthal), normalized SUM(Azimuthal Difference) values at each grid point.

SRD = SUM(Radial Difference), sum of the radial differences at each Cartesian grid point.

SRfilter = filtered SHEAR(Radial-RSA), shear values derived by imposing an uniform filter to the field of mean SHEAR(Radial) values.

SRmean = mean SHEAR(Radial-RSA), normalized SUM(Radial Difference) values at each grid point.

COSH = COMBINED SHEAR, combined shear as computed from the mean radial shear and the mean azimuthal shear, in 1/hr.

TPOW = THRESHOLD(Velocity Power), the received power above which velocities will be processed, in dB (5-10).

THCS = THRESHOLD(Combined Shear), the minimum combined shear value allowed for acceptance in the final shear field, in 1/hr (8-16).

XDIM = X-DIMENSION, the integral number of grid locations in the x-direction of the grid as determined by DOMAIN (X Size) and DOMAIN (Resolution).

XINazi = azimuthal X-INDEX, X-index corresponding to the transformation of the DIFFERENCE(Azimuthal) values in polar coordinates to the rectangular Cartesian coordinate system used for the shear fields.

YDIM = Y-DIMENSION, the integral number of grid locations in the y-direction of the grid as determined by DOMAIN (Y Size) and DOMAIN (Resolution).

YINDazi = azimuthal Y-INDEX, Y-index corresponding to the transformation of the DIFFERENCE(Azimuthal) values in polar coordinates to the rectangular Cartesian coordinate system used for the shear fields.

XINrad = radial X-INDEX, X-index corresponding to the transformation of the DIFFERENCE(Radial) values in polar coordinates to the rectangular Cartesian coordinate system used for the shear fields.

YINDrad = radial Y-INDEX, Y-index corresponding to the transformation of the DIFFERENCE(Radial) values in polar coordinates to the rectangular Cartesian coordinate system used for the shear fields.

Note: Precision is equivalent to the units unless otherwise stated.

3.2.2 SYMBOLIC FORMULAS

```
COMPUTE (AZIMUTH LIMITS)
    IF (|DXM+DXS| is less than DXS and |DYM+DYS| is less than
       DYS)
         THEN
         AZmin = 0 radians
         AZmax = 2   radians
    ELSE
         AZmin = MINIMUM(AZA1,AZA2,AZA3,AZA4)
         AZmax = MAXIMUM(AZA1,AZA2,AZA3,AZA4)
    END IF
   where AZA1 = $TAN^{-1}$(DXM/DYM)
         AZA2 = $TAN^{-1}$(DXM/(DYM+DYS))
         AZA3 = $TAN^{-1}$((DXM+DXS)/DYM)
         AZA4 = $TAN^{-1}$((DXM+DXS)/(DYM + DYS))
```

Note that these tangent function computations are to be made such that the resultant angles are placed in the quadrants consistent with the signs of the numerator and denominator.

```
COMPUTE (RANGE LIMITS)
     RSmax = MAXIMUM(R1,R2,R3,R4) + FLOAT (NSV/2)(RSSazi)
     IF (RSmax is greater than (MSR) (RSSazi))
     RSmax = (MSR) (RSSazi)
     END IF
     IF (|DXM+DXS| is less than DXS or |DYM+DYS| is less than
        DYS)
     THEN
           RSmin = 0

     ELSE
           RSmin = MINIMUM(R1,R2,R3,R4) - FLOAT (NSV/2)(RSSazi)
           IF (RSmin is less than 0)
           RSmin = 0
           END IF
     END IF
    where R1 = SQRT($DXM^2$ + $DYM^2$)
          R2 = SQRT($DXM^2$ + $(DYM + DYS)^2$)
          R3 = SQRT($(DXM + DXS)^2$ + $DYM^2$ )
          R4 = SQRT($(DXM + DXS)^2$ + $(DYM + DYS)^2$)

COMPUTE (X-DIMENSION)
      XDIM = nearest integer (DOMAIN(X Size)/DOR) + 1

COMPUTE (Y-DIMENSION)
      YDIM = nearest integer (DOMAIN(Y Size)/DOR) + 1
```

COMPUTE (average VELOCITY(Doppler))

$$VDavg_i = \sum_{j=i-\text{FLOAT }(NSV/2)}^{j=i+\text{FLOAT }(NSV/2)} VD_j / NGR_i$$

where i is the sample volume number, FLOAT (NSV/2) $\leq i \leq$ ((RSmax/RSSazi) + 1 - FLOAT (NSV/2)), and POW_j is greater than THRESHOLD(Velocity Power). NGR is equal to the number of data values contributing to VDavg and is computed by incrementing NGR for each good VD value that contributes to VDavg. NGR must be greater than FLOAT (NSV/2) for VDavg to be acceptable. Otherwise set VDavg to a default value.

COMPUTE (DIFFERENCE(Radial))

$$DR_{i,k} = VDavg_{(i+\text{ FLOAT }(NSV/2)),k} - VDavg_{(i,k)}$$

where i is the sample volume number, k the azimuth number, and where

FLOAT (NSV/2) $\leq i \leq$ ((RSmax/RSSazi) + 1 - FLOAT (NSV/2)). For DR to be valid both VDavg values must be valid, i.e. not equal to a default value.

COMPUTE (DIFFERENCE(Azimuthal))

$$DA_{i,k-.5}=(VDavg_{i,k} - VDavg_{i,k-1})/(RS_i \times (AZ_k - AZ_{k-1}))$$

where i is the sample volume number and k, the azimuth number. For DA to be valid, both VDavg values must be valid i.e. not equal to a default value.

COMPUTE (radial X-INDEX)

$$XINrad = ((RS_i \times \sin(AZ_k) \times \cos(PHI\#) - DXM)/DOR)$$

where i is the sample volume number and k, the azimuth number. This computation needs to be rounded to nearest whole number. Lower left corner of grid is assumed to have (0,0) indices.

COMPUTE (radial Y-INDEX)

$$YINDrad = ((RS_i \times \cos(AZ_k) \times \cos(PHI\#) - DYM)/DOR)$$

where i is the sample volume number and k, the azimuth number. This computation needs to be rounded to nearest whole number. Lower left corner of grid is assumed to have (0,0) indices.

COMPUTE (NUMBER(Potential Difference Radial))

$$NPDR_{XINrad,YINDrad} = NPDR_{XINrad,YINDrad} + 1$$

where incrementing is performed for computation of each (XINrad,YINDrad) pair.

COMPUTE (azimuthal X-INDEX)

$XINazi = ((RS_i \times \sin((AZ_k + AZ_{k-1})/2) \times \cos(PHI\#) - DXM)/DOR)$

where i is the sample volume number and k, the azimuth number. This computation needs to be rounded to nearest whole number. Lower left corner of grid is assumed to have (0,0) indices.

COMPUTE (azimuthal Y-INDEX)

$YINDazi = ((RS_i \times \cos((AZ_k + AZ_{k-1})/2) \times \cos(PHI\#) - DYM)/DOR)$

where i is the sample volume number and k, the azimuth number. This computation needs to be rounded to nearest whole number. Lower left corner of grid is assumed to have (0,0) indices.

COMPUTE (NUMBER(Potential Difference Azimuthal))

$NPDA_{XINazi,YINDazi} = NPDA_{XINazi,YINDazi} + 1$

where incrementing is performed for computation of each (XINazi,YINDazi) pair.

COMPUTE (SUM(Radial Difference))

$SRD_{XINrad,YINDrad} = SRD_{XINrad,YINDrad} + DR_{i,k}$

where i and k are the sample volume and azimuth numbers respectively and DR is not equal to the default value.

COMPUTE (NUMBER(Radial Difference))

$NRD_{XINrad,YINDrad} = NRD_{XINrad,YINDrad} + 1$

where incrementing is performed only when a SRD is computed.

COMPUTE (SUM(Azimuthal Difference))

$SAD_{XINazi,YINDazi} = SAD_{XINazi,YINDazi} + DA_{i,k}$

where i and k are the sample volume and radial numbers respectively and DA is not equal to the default value.

COMPUTE (NUMBER(Azimuthal Difference))

$NAD_{XINazi,YINDazi} = NAD_{XINazi,YINDazi} + 1$

where incrementing is performed only when a SAD is computed.

COMPUTE (mean SHEAR(Radial-RSA))

$SRmean_{l,m} = SRD_{l,m} / (NRD_{l,m} \times RSSazi \times NSV)$

where l and m are the indices in x and y respectively.

COMPUTE (mean SHEAR(Azimuthal))

$SAmean_{l,m} = SAD_{l,m} / NAD_{l,m}$

where l and m are the indices in x and y respectively. If NAD equals 0 then SAmean is set to 0.

COMPUTE (filtered SHEAR(Radial-RSA))

$$SRfilter_{l,m} = \sum_{i=-p}^{i=p} \sum_{j=-p}^{j=p} SRmean_{l+i,m+j} /CFLR$$

where l and m are the indices in x and y respectively and p = (sqrt(NFL) - 1)/2, and where SR $mean_{l+i,\ m+j}$ is not equal to FLAG VALUE, and where CFLR is incremented for each SR $mean_{l+i,\ m+j}$ that is not equal to FLAG VALUE.

IF CFLR equals zero then set SRfilter (l,m) to FLAG VALUE.

COMPUTE (filtered SHEAR(Azimuthal))

$$SAfilter_{l,m} = \sum_{i=p}^{i=p} \sum_{j=p}^{j=p} SAmean_{l+i,m+j} /CFLA$$

where l and m are the indices in x and y respectively and p = (sqrt(NFL) - 1)/2, and where $SAmean_{l+i,\ m+j}$ is not equal to FLAG VALUE, and where CFLA is incremented for each SA $mean_{l+i,\ m+j}$ that is not equal to FLAG VALUE.

IF CFLA equals zero then set SAfilter (l,m) to FLAG VALUE.

COMPUTE (COMBINED SHEAR)

```
IF ($SRfilter_{l,m}$ is not equal to FLV)
THEN
COSH$_{l,m}$ = $SRfilter_{l,m}^2$
ELSE
COSH$_{l,m}$ = 0
END IF

IF ($SAfilter_{l,m}$ is not equal to FLV)
THEN
COSH$_{l,m}$ = $COSH_{l,m} + SAfilter_{l,m}^2$
IF ($COSH_{l,m}$ is greater than zero)
THEN
COSH$_{l,m}$ = SQRT($COSH_{l,m}$)
```

```
ELSE
IF (SRfilter$_{l,m}$ is equal to FLV AND SAfilter$_{l,m}$ is equal to
   FLV)
THEN
COSH$_{l,m}$ = FLV
END IF
```

where l and m are the indices in x and y respectively.

4.0 OUTPUT

4.1 IDENTIFICATION

The field COMBINED SHEAR contains values of the combined shear of the radial velocities as measured by the Doppler radar. This shear field is organized onto a rectangular Cartesian grid with origin (lower left corner) at (DXM,DYM) where these coordinates are relative to the radar.

4.2 DISTRIBUTION

The values of COMBINED SHEAR may be easily mapped for display or may be used as input for higher level routines.

5.0 INFERENCES

5.1 LIMITATIONS

No major limitations are noted at this time.

5.2 FUTURE DEVELOPMENTS

No further development is anticipated on this particular algorithm. However, the output from this algorithm will be exploited in terms of developing hazard products. In addition, the site-adaptable parameters should be explored further with respect to determination of optimum values.

CROSS-CORRELATION TRACKING
ALGORITHM DESCRIPTION
NX-DR-03-034/03

1.0 PROLOGUE

1.1 FUNCTIONAL DESCRIPTION

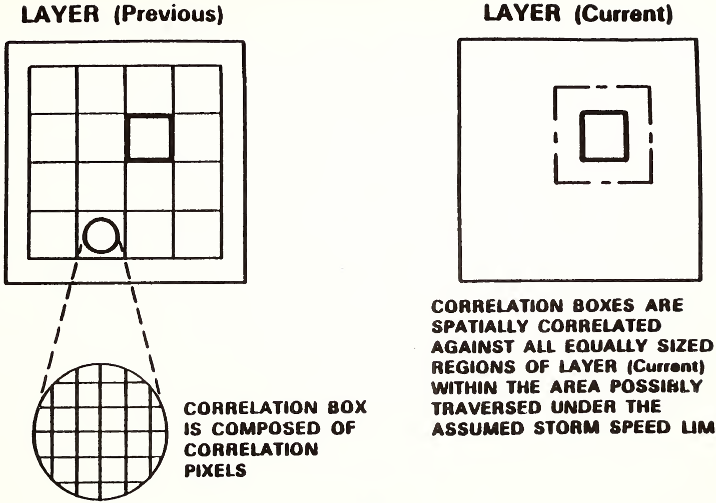
This algorithm generates an estimated velocity field for the reflectivity features contained in the LAYER COMPOSITE REFLECTIVITY product. Velocity estimates are obtained by a cross-correlation pattern tracking technique operating upon thresholded reflectivity fields obtained from the LAYER COMPOSITE REFLECTIVITY products generated by two consecutive volume scans. The user requesting the algorithm may specify the altitude regime, from those available for LAYER COMPOSITE REFLECTIVITY, to be operated upon.

The algorithm is intended to serve as a complement to the STORM POSITION FORECAST [008] algorithm. Evaluations conducted at Lincoln Laboratories have shown that the cross-correlation tracking technique performs well in environments characterized by extended storms (e.g. squall lines) and stratiform precipitation, while suffering degraded performance in synoptic conditions characterized by compact storms and moderate-to-high levels of convection - the strengths and weaknesses of the STORM POSITION FORECAST algorithm ("centroid tracker"), which may be thought of as tracking point targets, are the converse of those of the cross-correlation tracker. (1). Additional evaluations have indicated that, in the presence of extended storms or stratiform precipitation, cross-correlation tracking performs comparably on thresholded and unthresholded reflectivity data.

The algorithm performs the following operations (See Figure 1):

1) Layered, cartesian, reflectivity fields generated from the two most recent volume scans are obtained; and a reflectivity threshold is applied to create binary (i.e. taking on values zero or one) fields. The more recent field is referred to as LAYER (Current), the other as LAYER (Previous).

2) On the basis of an assumed speed limit for reflectivity features in LAYER (Previous) and the time interval between the LAYERs, margins are established on LAYER (Previous) to exclude features in the reflectivity field which may have moved out of the spatial region covered by the LAYERs in that intervening time interval from the algorithm's purview. LAYER (Previous) is then subdivided into "Correlation Boxes", 28.0 km on a side, which are the regions to be tracked by the algorithm.



LAYER (Previous)

LAYER (Current)

SUBDIVIDED
INTO ARRAY
OF "CORRELATION
BOXES" WITH
MARGIN

CORRELATION BOX
IS COMPOSED OF
CORRELATION
PIXELS

CORRELATION BOXES ARE
SPATIALLY CORRELATED
AGAINST ALL EQUALLY SIZED
REGIONS OF LAYER (Current)
WITHIN THE AREA POSSIBLY
TRAVERSED UNDER THE
ASSUMED STORM SPEED LIMIT

TYPICAL PARAMETERS:

CORRELATION BOX: 28 × 28 km
CORRELATION PIXEL: 4 × 4 km

Figure 1

3) For each Correlation Box containing more than a specified fraction of pixels above the reflectivity threshold, correlation coefficients are computed against each position in LAYER (Current) to which the Correlation Box could have moved, under the assumption of the speed limit mentioned in (2) above. The field of correlation coefficients has spatial resolution equal to that of the LAYERs. If the correlation coefficients for a Correlation Box are sufficiently significant, a quadratically interpolated peak location for the correlation field is computed and used to define the velocity of that Correlation Box.

4) Each Correlation Box not assigned a velocity in (3) above is then assigned a velocity equal to an inverse-distance-squared-weighted average of the Correlation Box velocities determined in (3).

1.2 SOURCE

This algorithm was developed at Lincoln Laboratories by Marc Goldburg. The algorithm is analogous to the correlation tracking algorithm reported in (1) below, but differs substantially in its use of thresholded data and in its displacement and velocity interpolation schemes.

REFERENCES

(1) Brasunas, J.C.; "A Comparison of Storm Tracking and Extrapolation Algorithms"; Lincoln Laboratory Project Report ATC-124; July 1984; (DOT-FAA-PM 84-1)

(2) Alaka, M.A., et. al; "Nowcasts and Short-Range (0-2 Hour) Forecast of Thunderstorms and Severe Convective Weather for Use in Air Traffic Control", Final Report; Technique Development Laboratory, National Weather Service; November 1979; (FAA-RD-79-98)

1.3 PROCESSING ENVIRONMENT

This algorithm requires input from the user and from the LAYER COMPOSITE REFLECTIVITY algorithm. Its output is primarily intended as an input to the STORM EXTRAPOLATION MAP algorithm.

2.0 INPUTS

2.1 IDENTIFICATION

LAYER (Current) = Layered reflectivity product generated from the volume scan immediately prior to the time that the algorithm is invoked - a uniform, horizontal cartesian grid of reflectivity pixels for any of the altitude extents available for the LAYER COMPOSITE REFLECTIVITY product, as specified by TYPE (Layer), units of dBZe.

LAYER (Previous) = Layered reflectivity product of the same TYPE (Layer) and format as LAYER (Current), but generated from the volume scan preceding that of LAYER (Current), units of dBZe.

LENGTH (Correlation Box) = The desired length of a side of a correlation box, units of kilometers.

PIXEL SIZE = Length of the side of a pixel in the LAYERs, units of kilometers.

SPACING (Correlation Box) = The desired spacing of correlation box centers in the row and column dimensions of LAYER (Previous), units of km.

SPEED (Storm Limit) = Maximum possible speed for reflectivity features in LAYER (Previous), units of km/hr.

THRESHOLD (Correlation) = Minimum value of a correlation coefficient to be accepted for displacement calculations.

THRESHOLD (dBZe) = Reflectivity threshold employed in creating binary fields from the two LAYERs, units of dBZe.

THRESHOLD (Pixel Fraction) = The minimum fraction of above-THRESHOLD (dBZe) Pixels required in a LAYER(Previous) correlation box for a correlation-based displacement to be computed for that Box.

TIME (Current) = The time at which the volume scan generating LAYER (Current) was collected, units of hr.

TIME (Previous) = The time at which the volume scan generating LAYER (Previous) was collected, units of hr.

TYPE (Layer) = Indicates which of the available altitude regimes for the LAYER COMPOSITE REFLECTIVITY product is desired for LAYER (Current) and LAYER (Previous).

ADAPTABLE PARAMETER VALUES AND RANGES

Parameter	Site Adjus.	User Selec.	Suggested Value	Allowable Range
LENGTH (Correlation Box)	X		28.0 km	
SPACING (Correlation Box)	X		28.0 km	20.0 km - 28.0 km
SPEED (Storm Limit)	X		120 km/hr	80 - 120 km/hr
THRESHOLD (Correlation)	X		0.55	0.50 - 0.70
THRESHOLD (dBZe)	X		25.0 dBZe	20.0 - 35.0 dBZe
THRESHOLD (Pixel Fraction)	X		0.25	0.15 - 0.30
TYPE (Layer)		X	Lowest altitude regime for LAYER COMPOSITE REFLEC. including 18 kft	all LAYER COMPOSITE REFLECTIVITY altitude layers

2.2 ACQUISITION

LAYER (Current), LAYER (Previous), TIME (Current), TIME (Previous), and PIXEL SIZE are obtained from the LAYER COMPOSITE REFLECTIVITY algorithm.

TYPE (Layer) is a user-specified parameter, for each request from the algorithm.

LENGTH (Correlation Box), SPACING (Correlation Box), SPEED (Storm Limit), THRESHOLD (Correlation), THRESHOLD (dBZe) and THRESHOLD (Pixel Fraction) are site-adaptable parameters.

3.0 PROCEDURE

3.1 ALGORITHM

```
BEGIN ALGORITHM (CROSS-CORRELATION TRACKING)

1.0  COMPUTE (PIXEL NUMBER)
     COMPUTE (OVERLAP)
     COMPUTE (DISTANCE (Maximum Lag))
     COMPUTE (THRESHOLD (Good Pixels))

2.0  DO FOR ALL (pixels in LAYER (Previous))
        READ (REFLECTIVITY (Pixel))
        IF ((REFLECTIVITY (Pixel) is greater than or equal
             to THRESHOLD (dBZe))
        THEN
           (Set this pixel's value to be one in LAYER
           (Previous))
        ELSE
          (Set this pixel's value to be zero in LAYER
          (Previous))
        END IF
     END DO

3.0  DO FOR ALL (pixels in LAYER (Current))
        READ (REFLECTIVITY (Pixel))
        IF ((REFLECTIVITY (Pixel) is greater than or equal
             to THRESHOLD (dBZe))
        THEN
           (Set this pixel's value to be one in LAYER
           (Current))
        ELSE
           (Set this pixel's value to be zero in LAYER
           (Current))
        END IF
     END DO

4.0  (Establish margins of DISTANCE (Maximum Lag) pixels
     along the four borders of LAYER (Previous).  Within
     these margins, identify Correlation Boxes -- subarrays
     of LAYER (Previous): uniformly spaced in the row and
     column dimensions of LAYER (Previous); containing
     PIXEL NUMBER pixels to a side; and overlapping each
     other in the row and column dimensions by OVERLAP rows
     and columns, respectively.)

5.0  DO FOR ALL (Correlation Boxes in LAYER (Previous))
        IF ((Number of non-zero pixels in the Correlation
             Box) is greater than or equal to THRESHOLD (Good
             Pixels))
        THEN
```

```
5.1  DO FOR ALL (Displacements of the Correlation
                 Box's position in LAYER (Current)
                 with respect to its position in LAYER
                 (Previous), from minus to plus
                 DISTANCE (Maximum Lag) in the row
                 and column dimensions)
       5.1.1  COMPUTE (CORRELATION (Box Displacement))
       5.1.2  WRITE ((CORRELATION (Box Displacement)
                    to FIELD (Correlations))
       5.1.3  IF (current CORRELATION (Box Displacement) is
                 the most positive CORRELATION (Box Dis-
                 placement) computed for this Correlation
                 Box)
              THEN
                      WRITE (current row displacement to
                             ROW DISPLACEMENT (Correlation
                             Maximum))
                      WRITE (current column displacement
                             to COLUMN DISPLACEMENT (Cor-
                             relation Maximum))
              END IF
     END DO

5.2  IF (the CORRELATION (Box Displacement) at ROW
         DISPLACEMENT (Correlation Maximum) and COLUMN
         DISPLACEMENT (Correlation Maximum), and the
         CORRELATION (Box Displacement)s at the nearest
         four displacements to that point, are all no
         less than THRESHOLD (Correlation))
     THEN
       5.2.1  COMPUTE (ROW DISPLACEMENT (Interpolated))
              COMPUTE (ROW VELOCITY)
       5.2.2  COMPUTE (COLUMN DISPLACEMENT (Interpolated))
              COMPUTE (COLUMN VELOCITY)
       5.2.3  WRITE (coordinates of Correlation Box center
                    to VELOCITIES (Correlation))
              WRITE (ROW VELOCITY as East/West velocity
                    of Correlation Box to VELOCITIES
                    (Correlation))
              WRITE (COLUMN VELOCITY as North/South
                    velocity of Correlation Box to
                    VELOCITIES (Correlation))
     ELSE
              WRITE (coordinates of Correlation Box center
                   to VELOCITIES (Correlation))
              (Note that velocities were not determined
              for this Correlation Box)
     END IF
```

```
          ELSE
             WRITE (coordinates of Correlation Box center to
                   VELOCITIES (Correlation))
             (Note that velocities were not determined for this
             Correlation Box)
          END IF
       END DO

6.0    IF (all Correlation Boxes have undetermined velocities)
       THEN
          (Note that no velocities can be determined from
          LAYER (Current) and LAYER (Previous))
          EXIT
       END IF

7.0    DO FOR ALL (Correlation Boxes with undetermined velo-
                  cities)
       7.1  COMPUTE (INTERPOLATED VELOCITY (Column))
            WRITE (INTERPOLATED VELOCITY (Column) as
                   North/South velocity for this Correlation
                   Box to VELOCITIES (Correlation))
       7.2  COMPUTE (INTERPOLATED VELOCITY (Row))
            WRITE (INTEPOLATED VELOCITY (Row) as East/West
                   velocity for this Correlation Box to
                   VELOCITIES (Correlation))
       END DO

8.0    WRITE (VELOCITIES (Correlation))
       WRITE (TIME (Current))
       WRITE (TIME (Previous))
       WRITE (THRESHOLD (dBZe))
       WRITE (TYPE (Layer))
END ALGORITHM  (CROSS-CORRELATION TRACKING)
```

.2 COMPUTATION

3.2.1 NOTATION

COC [Real-Valued] = CORRELATION (Box Displacement), the coefficient of correlation between the thresholded data of a correlation box in LAYER (Previous) and an equally-sized array of data in LAYER (Current). Precise to 10^{-6} units.

DML [Integer-Valued] = DISTANCE (Maximum Lag), the displacement of an object moving at SPEED (Storm Limit) for a time interval equal to that between LAYER (Previous) and LAYER (Current), units of correlation pixels. Precise to 1 correlation pixel.

DPCI [Real-Valued] = COLUMN DISPLACEMENT (Interpolated), quadratic estimate of peak location in correlation surface sampled in FIELD (Correlation) in the column dimension, units of correlation pixels. Precise to 10^{-4} correlation pixels.

DPCM [Integer-Valued] = COLUMN DISPLACEMENT (Correlation Maximum), column displacement of the correlation box in LAYER (Previous) yielding the maximum value of CORRELATION (Box Displacement), units of correlation pixels. Precise to 1 correlation pixel.

DPRI [Real-Valued] = ROW DISPLACEMENT (Interpolated), quadratic estimate of peak location in correlation surface sampled in FIELD (Correlation) in the row dimension, units of correlation pixels. Precise to 10^{-4} correlation pixels.

DPRM [Integer-Valued] = ROW DISPLACEMENT (Correlation Maximum), row displacement of the correlation box in LAYER (Previous) yielding the maximum value of CORRELATION (Box Displacement), units of correlation pixels. Precise to 1 correlation pixel.

DSQB [Real-Valued] = DISTANCE SQUARED (Box), the distance, squared, from the correlation box with undetermined velocities in Section 6.0 of the algorithm to a correlation box whose velocities were computed in Section 5.0, units of km^2. Precise to $0.1\ km^2$.

FLC [Real-Array] = FIELD (Correlations), an array of the same dimensions, spatial resolution and orientation as the correlation box subarrays of LAYER (Previous), containing the field of CORRELATION (Box Displacement) computed for this correlation box. Precise to 10^{-6} units for each entry.

LAYC [Real-Array] = LAYER (Current), a uniform, two-dimensional, array containing reflectivity values representative of measured radar reflectivity over some altitude regime, above the earth for a given region. The reflectivity data are assumed to be expressed in units of dBZe. Data orientation within the array is assumed to be North "up" - other orientations will require appropriate modifications of the expressions for North/South and East/West oriented quantities. Row and column indices MUST increment by one from row-to-row and column-to-column as the array is traversed from the upper-left-hand corner in the row and column dimensions, respectively. Precise to 1.0 dBZe for each entry.

LAYP [Real-Array] = LAYER (Previous), an array of reflectivity values with the same orientation, origin, resolution and indexing scheme as LAYER (Current). Precise to 1.0 dBZe for each entry.

LEC [Real-Valued] = LENGTH (Correlation Box), the desired length of a side of a correlation box, units of kilometers. Precise to 1.0 km.

OVE [Integer-Valued] = OVERLAP, the overlap, in either dimension of LAYER (Previous), of correlation boxes, units of correlation pixels. Precise to 1 correlation pixel.

PIX [Integer-Valued] = PIXEL NUMBER, the number of correlation pixels to a side of a correlation box. Precise to 1 correlation pixel.

PS [Real-Valued] = PIXEL SIZE, length of the side of a pixel in the LAYERs, units of kilometers. Precise to 10^{-3} km.

SPC [Real-Valued] = SPACING (Correlation Box), the desired spacing of correlation box centers in the row and column dimensions of LAYER (Previous), units of km. Precise to 0.1 km.

SPL [Real-Valued] = SPEED (Storm Limit), maximum possible speed for reflectivity features in LAYER (Previous), units of km/hr. Precise to 1.0 km/hr.

TCUR [Real-Valued] = TIME (Current), the time at which the volume scan generating LAYER (Current) was collected, units of hr. Precise to 10^{-5} hr.

TGP [Integer-Valued] = THRESHOLD (Good Pixels), THRESHOLD (Pixel Fraction) normalized by the number of pixels in a correlation box, units of correlation pixels. Precise to 1 correlation pixel.

TPF [Real-Valued] = THRESHOLD (Pixel Fraction), the minimum fraction of above-THRESHOLD (dBZe) Pixels required in a LAYER (Previous) correlation box for a correlation-based displacement to be computed for that Box. Precise to 10^{-3} units.

TPRE [Real-Valued] = TIME (Previous), the time at which the volume scan generating LAYER (Previous) was collected, units of hr. Precise to 10^{-5} hr.

VELC [Real-Valued] = COLUMN VELOCITY, Correlation-based estimate of the velocity of a correlation box in the column dimension of LAYER (Previous), units of km/hr. Precise to 10^{-3} km/hr.

VELR [Real-Valued] = ROW VELOCITY, Correlation-based estimate of the velocity of a correlation box in the row dimension of LAYER (Previous), units of km/hr. Precise to 10^{-3} km/hr.

VEL [Data-Table] = VELOCITIES (Correlation), a table containing the coordinates, (km East of radar, km North of radar), of each correlation box's center as well as its velocity estimates (km/hr East, km/hr North). Position is precise to 0.1 km East and 0.1 km North for each entry. Velocity is precise to 10^{-3} km/hr East and 10^{-3} km/hr North for each entry.

IVEC [Real-Valued] = INTERPOLATED VELOCITY (Column), the interpolated, column-dimension, velocity of a correlation box, computed in the absence of a correlation-based velocity, units of km/hr. Precise to 10^{-3} km/hr.

IVER [Real-Valued] = INTERPOLATED VELOCITY (Row), the interpolated, row-dimension, velocity of a Correlation Box, computed in the absence of a correlation-based velocity, units of km/hr. Precise to 10^{-3} km/hr.

ZPI [Real-Valued] = REFLECTIVITY (Pixel), reflectivity value of a pixel in LAYER (Previous) LAYER (Current), units of dBZe. Precise to 1.0 dBZe.

ZTPC [Integer-Valued] = THRESHOLDED PIXEL (Current), the thresholded (i.e. zero or one) reflectivity value of the correlation pixel in LAYER (Current) overlaid by the correlation pixel with value ZTPP in the current correlation box of LAYER (Previous) at its current displacement. Precise to 1 unit.

ZTPP [Integer-Valued] = THRESHOLDED PIXEL (Previous), the thresholded (i.e. zero or one) reflectivity value of a correlation pixel in the current correlation box of LAYER (Previous). Precise to 1 unit.

3.2.2 SYMBOLIC FORMULAE

Precision in this section will be as follows:

1) All floating point quantities, when considered as logarithms to the base 10, shall possess a mantissa accuracy of 5 significant decimal places and a possible range of characteristic values from -20 to +20 (decimal).

2) All integral valued quantities shall possess an accuracy of one unit.

3) Any arithmetic computation involving one or more floating point quantities shall be carried out with floating point arithmetic exclusively.

4) No conversion of a floating point quantity to an integral valued quantity shall introduce an absolute error greater than 0.5 units in the integral representation relative to the floating point representation.

NOTE: square brackets "[]" are used to denote the operation of rounding a real-valued expression to the value of the nearest integer. For some real-valued expression, X:

$$[X] = SGN(X)\ \{FLOOR(|\ X + (0.5)SGN(X)\ |)\}$$

where

$$SGN(X) = \begin{matrix} +1 & | & X \text{ greater than or equal to } 0 \\ -1 & | & X \text{ less than } 0 \end{matrix}$$

and

FLOOR (|X|) is the largest integer less than or equal to X .

COMPUTE (COLUMN DISPLACEMENT (Interpolated))

$$DPCI = DPCM + (0.5)\ \frac{\{FLC(DPRM,(DPCM-1)) - FLC(DPRM,(DPCM+1))\}}{\{FLC(DPRM,(DPCM-1)) + FLC(DPRM,(DPCM+1)) - (2)\ FLC(DPRM,DPCM)\}}$$

NOTE: In the event that the denominator of the term on the right equals zero, DPCI = DPCM.

COMPUTE (COLUMN VELOCITY)

VELC = (DPCI) (PS) / (TCUR - TPRE)

COMPUTE (CORRELATION (Box Displacement))

$$\mathrm{COC} = \frac{\frac{1}{N}\sum_{i=1}^{N}(\mathrm{ZTPP}_i)(\mathrm{ZTPC}_i) - \left(\frac{1}{N}\right)^2\left(\sum_{i=1}^{N}\mathrm{ZTPP}_i\right)\left(\sum_{i=1}^{N}\mathrm{ZTPC}_i\right)}{\frac{1}{N}\left\{\left(\sum_{i=1}^{N}\mathrm{ZTPP}_i\right)\left(\sum_{i=1}^{N}\mathrm{ZTPC}_i\right)\left(1-\frac{1}{N}\sum_{i=1}^{N}\mathrm{ZTPP}_i\right)\cdot\left(1-\frac{1}{N}\sum_{i=1}^{N}\mathrm{ZTPC}_i\right)\right\}^{1/2}}$$

where N is the number of correlation pixels in a correlation box; and the ZTPP_i and ZTPC_i are the thresholded values of those correlation pixels.

NOTE: If $N = \sum_{i=1}^{N} \mathrm{ZTPP}_i$ or $N = \sum_{i=1}^{N} \mathrm{ZTPC}_i$,

$$\text{then } \mathrm{COC} = \frac{1}{N}\,\mathrm{MIN}\left\{\sum_{i=1}^{N}\mathrm{ZTPP}_i,\ \sum_{i=1}^{N}\mathrm{ZTPC}_i)\right\}$$

COMPUTE (DISTANCE (Maximum Lag))

DML = [(TCUR - TPRE)(SPL/PS)]

COMPUTE (INTERPOLATED VELOCITY (Column))

$$\mathrm{IVEC} = \left\{\sum_{i=1}^{N}\frac{1}{\mathrm{DSQB}_i}\right\}^{-1}\left\{\sum_{i=1}^{N}\frac{\mathrm{VELC}_i}{\mathrm{DSQB}_i}\right\}$$

where N is the number of correlation boxes with defined velocities prior to the execution of Section 7.0 of the algorithm.

COMPUTE (INTERPOLATED VELOCITY (Row))

$$\text{IVER} = \left\{ \sum_{i=1}^{N} \frac{1}{\text{DSQB}_i} \right\}^{-1} \left\{ \sum_{i=1}^{N} \frac{\text{VELR}_i}{\text{DSQB}_i} \right\}$$

where N is the number of correlation boxes with defined velocities prior to the execution of Section 7.0 of the algorithm.

COMPUTE (OVERLAP)

OVE = [-SPC/PS + PIX]

COMPUTE (PIXEL NUMBER)

PIX = [(LEC/PS)]

COMPUTE (ROW DISPLACEMENT (Interpolated))

$$\text{DPRI} = \text{DPRM} + (0.5) \frac{\{\text{FLC}((\text{DPRM}-1),\text{DPCM}) - \text{FLC}((\text{DPRM}+1),\text{DPCM})\}}{\{\text{FLC}((\text{DPRM}-1),\text{DPCM}) + \text{FLC}((\text{DPRM}+1),\text{DPCM}) - (2)\ \text{FLC}\ (\text{DPRM},\text{DPCM})\}}$$

NOTE: In the event that the denominator of the term on the right equals zero, DPRI = DPRM.

COMPUTE (ROW VELOCITY)

VELR = (DPRI) (PS) / (TCUR - TPRE)

COMPUTE (THRESHOLD (Good Pixels))

TGP = [(PIX • PIX)(TPF)]

4.0 OUTPUTS

4.1 IDENTIFICATION

VELOCITIES (Correlation) is a table containing an estimated velocity vector field corresponding to the reflectivity field of LAYER (Previous). Each entry in the table consists of the location of the velocity vector's root in kilometers East and North of the radar, and the velocity vector components, in units of kilometers/hour, in the East and North directions.

TIME (Current) and TIME (Previous) are the times at which the volume scans generating LAYER (Current) and LAYER (Previous), respectively, were collected.

TYPE (Layer) is a user-specified parameter, indicating the altitude regime encompassed by the LAYERs.

THRESHOLD (dBZe) is the site-adjustable reflectivity threshold employed by the algorithm.

4.2 DISTRIBUTION

The output of this algorithm is primarily intended as an input to the STORM EXTRAPOLATION MAP algorithm, to be employed in the generation of extrapolated reflectivity maps in situations where the synoptic meteorology is characterized by extended storms (e.g. squall lines) and/or stratiform precipitation.

The algorithm's output may also prove to be useful in the estimation of the horizontal wind fields in environments with minimal convective activity.

.0 INFERENCES

5.1 LIMITATIONS

The algorithm incorporates two basic assumptions:

1) The reflectivity field is subject, primarily, to advection in the time interval between LAYER (Previous) and LAYER (Current).

   -- Cross-correlation tracking, as described in the preceding sections, may be thought of as a pattern tracking operation. The algorithm will perform most reliably when the movement of the patterns (i.e. features in the reflectivity field) may be characterized as translations. The algorithm's performance will be degraded in environments characterized by substantial levels of convective activity (e.g. propogation, convective growth and decay).

2) Features in the reflectivity field are large compared to the size of the pixels in LAYER (Previous) and LAYER (Current).

   -- The reflectivity thresholding operation performed prior to the computations of the correlation coefficients removes the majority of the "fine scale" information in the reflectivity field. This thresholding effectively focuses the tracker's attention on large-scale reflectivity features. Thus, while the tracker performs well in extended storm environments (e.g. squall lines and stratiform precipitation), it should not be employed in the presence of isolated, compact convective storms. That type of environment dictates the sort of tracking logic incorporated in the STORM POSITION FORECAST [008] algorithm which may be considered to track "point targets". Evaluations conducted at Lincoln Laboratories have indicated that, in extended storm environments, correlation tracking using thresholded reflectivity data performs comparably to correlation tracking on the unthresholded reflectivity field.

Correlation computations necessarily operate on large numbers of data. Insensitivity to the computational advantages provided by binary (i.e. thresholded) data fields may result in unwarranted processing requirements for a particular implementation of the algorithm. In particular, the presence of binary data should reduce many of the arithmetic operations required in the computation of the correlation coefficients to logical tests. Additionally, a single look-up table should be employed for the interpolation of undetermined velocities in Section 7.0 of the algorithm. The Correlation Boxes are generated on a uniform grid; thus, it is necessary only to compute the possible distances from one Correlation Box to any other (there are 1+2+ ... +Square Root (# of Correlation Boxes) of them) for an arbitrary grid interval - the actual grid interval, be it 28 km or 5 km or ..., will not affect the final values of the interpolated velocities. This table should be built once, prior to the execution of 7.0.

Evaluations conducted at Lincoln Laboratories indicate run times for this algorithm, with surrogate LAYER COMPOSITE REFLECTIVITY out to a 180 km range and excluding I/O time, of 3.5 sec. on a Perkin-Elmer 3242 mini-computer.

5.2 FUTURE DEVELOPMENTS

T.B.D.

SECTION 3.0

Introduction to NEXRAD Algorithm Data Dictionary

MAJOR REVISIONS SINCE MAY 1984

Data Dictionaries

1. A tutorial on meteorological directions has been added to section II.3 of the Introduction to the NEXRAD Algorithm Data Dictionary.

2. Data element names, symbols and definitions have been changed as necessary to establish uniqueness. The following pages itemize these changes.

OLD DATA ELEMENT NAME	SYMBOL	ALGORITHM NO.	NEW DATA ELEMENT NAME	SYMBOL
beginning AZIMUTH	AZbeg	2	beginning pattern vector AZIMUTH	AZbegpv
beginning AZIMUTH	AZbeg	26	Beginning feature AZIMUTH	AZbegfe
ending AZIMUTH	AZend	2	ending pattern vector AZIMUTH	AZendpv
ending AZIMUTH	AZend	26	ending feature AZIMUTH	AZendfe
HEIGHT	H	2	HEIGHT(Feature Center)	HFC
HEIGHT	H	13	HEIGHT(Echo Tops)	HTOP
HEIGHT	H	7	HEIGHT(VAD Wind Estimate)	HVAD
HEIGHT	H	24	HEIGHT(Divergence Feature Center)	HDFC
HEIGHT	H	26	HEIGHT(TVS Feature)	HTVS
HEIGHT(Centroid)	HC	5, 12	HEIGHT(Storm Component-Centroid)	HSCC
HEIGHT(Centroid) difference	HCdif	5, 9	HEIGHT(Storm Component-Centroid) difference	HSCCdif
maximum LIQUID WATER(Integrated)	VILmax	15	maximum LIQUID WATER(Integrated-SWP)	VILSmax
RANGE(Slant)	RS	12	RANGE(Slant-Storm Component)	RSSC
beginning RANGE(Slant)	RSbeg	24	beginning RANGE(Slant Pattern Vector)	RSPVbeg
beginning RANGE(Slant)	RSbeg	2, 26	beginning RANGE(Slant-Feature)	RSFEbeg
beginning RANGE(Slant)	RSbeg	5	beginning RANGE(Slant-Storm Segment)	RSSSbeg
ending RANGE(Slant)	RSend	2, 26	ending RANGE(Slant-Feature)	RSFEend
ending RANGE(Slant)	RSend	24	ending RANGE(Slant Pattern Vector)	RSPVend
ending RANGE(Slant)	RSend	5	ending RANGE(Slant-Storm Segment)	RSSSend

OLD DATA ELEMENT NAME	SYMBOL	ALGORITHM NO.	NEW DATA ELEMENT NAME	SYMBOL
REFLECTIVITY FACTOR	Z	6, 22	REFLECTIVITY FACTOR(ZE)	ZE
REFLECTIVITY(Equivalent)	ZE	11,17,18,22, 23,24,29	REFLECTIVITY FACTOR(DBZE)	DBZE
maximum REFLECTIVITY(Equivalent)	ZEmax	5, 9, 22	maximum REFLECTIVITY FACTOR(DBZE)	DBZEmax
SECTOR	SEC	11	SECTOR(Transverse Wind)	STW
THRESHOLD(High Shear)	THS	2	THRESHOLD(Mesocyclone-High Shear)	TMHS
THRESHOLD(High Shear)	THS	24	THRESHOLD(Divergence-High Shear)	TDHS
THRESHOLD(Low Shear)	TLS	2	THRESHOLD(Mesocyclone-Low Shear)	TMLS
THRESHOLD(Low Shear)	TLS	24	THRESHOLD(Divergence-Low Shear)	TDLS
minimum THRESHOLD(Reflectivity)	THRmin	22	THRESHOLD(Minimum Reflectivity-2)	THR2
minimum THRESHOLD(Reflectivity)	THRmin	17	minimum THRESHOLD(Reflectivity-1)	THRmin1
maximum VELOCITY	Vmax	9, 5	maximum VELOCITY(Doppler)	VDmax
X-POSITION	X	5, 8	X-POSITION(Centroid)	XC
X-POSITION	X	11	X-POSITION(Box)	XB
X-POSITION(Centroid)	XC	5, 12	X-POSITION	X
forecasted X-POSITION	Xfor	8	forecasted X-POSITION(Centroid)	XCfor
Y-POSITION	Y	11	Y-POSITION(Box)	YB
Y-POSITION	Y	8	Y-POSITION(Centroid)	YC
forecasted Y-POSITION	Yfor	8	forecasted Y-POSITION(Centroid)	YCfor
Y-POSITION(Centroid)	YC	5, 12	Y-POSITION	Y

I. Purpose

The NEXRAD Algorithm Data Dictionary defines the data elements appearing in each of the algorithms. The obvious function of a dictionary is to define data elements for the novice. Although this is a valid function, this data dictionary was generated primarily to function as a cross-reference between algorithms thus facilitating the standardization of data element names and definitions during the creation of the Algorithm Report.

II. Methodology

In order to separate the data elements from the algorithms and then consolidate them into a data base, a set of attributes has been assigned to each data element. These attributes are:

Name - A representative title given to a data element.

Identifier Number - A unique number assigned to each data element within the data base.

Symbol - A character, or group of characters, representing a data element in a mathematical equation.

Units - The physical representation of a data element in mass, space, and time.

Value - A numerical quantity given to a data element.

Definition - A statement of the meaning of a data element.

Category - A grouping that most closely represents a data element's function, value or purpose.

Class - The mode in which a data element is utilized within or between algorithms.

Algorithm Number - A unique number assigned to each algorithm.

1. Name

Names are developed in such a way as to provide a clue to the definition associated with it. Following the name may be a "specifier". The specifier is used to modify a generic name, for example:

	Name	Specifier
Horizontal range:	RANGE	(Horizontal)
Slant range:	RANGE	(Slant)

By using this format, like terms are grouped together when listed alphabetically. Note that the entire name is capitalized and only the first letter of the specifier is capitalized. In many cases names are unique, that is, there is no specifier following it.

2. Symbol

Symbols are created to represent data elements within mathematical processes. Symbols are generally comprised of the first letter, or selected "key" letters within a name. "Key" means the first letter of the first three words in a name, or the first one, two, or three letters of the first word and the first letter of the second word (if necessary). Exceptions occur where more than one element requires the same "key" letters. Also, Greek letters are used as symbols for elements that are conventionally indicated in that manner. Within the dictionary Greek symbols are represented as words, not symbols. A pound sign (#) follows words that should be converted to symbols, e.g., PHI# is ϕ. Examples include:

STORM is ST
STORM TOP is STT

exceptions are:

STORM TILE is STI
ELEVATION is ϕ

A system of symbol qualifiers has been developed to identify and associate similar data elements within mathematical equations. Qualifiers are employed in cases where a data item is tagged with a trait that sets it apart from its generic counterpart.

For example:

B is the generic symbol for BIAS.
Bpre is the previous BIAS.
Bcur is the current BIAS.
Bfor is the forecasted BIAS.

Note: qualifier symbols are represented in lower case. The list of qualifiers is:

Name	Three Letter Symbol
Adjusted	adj
After	aft
Average	avg
Backward	bac
Before	bef
Beginning	beg
Current	cur
Difference	dif
Displacement	dis
Effective	eff
Ending	end
Forecasted	for
Forward	fwd
Highest	hgh
Interpolated	int
Lowest	low
Maximum	max
Middle	mid
Minimum	min
Optimum	opt
Partial	par
Previous	pro
Propagated	pro
Reference	ref
Reset	res
Total	tot
Unordered	uno

List of Indices:

i - Elevation
j - Azimuth
k - Ranges
l - Counter #3
m - Counter #2
n - Counter #1

The symbol Q1, Q2, Q3 ... etc. will be used as a dummy variable for sub-equations to be input into a main equation.

3. Units and Coordinates

Meteorological coordinates along with a kilograms, kilometers, hours, and radians system of units is employed. Standard meteorological units should occur for most displays. For example: (a) wind speed is expressed in km/hr in internal alorithm processing and should be converted to m/sec for display, and (b) wind direction is expressed in radians during internal algorithm processing and should be converted to degrees for display. Note that the direction reference in engineering coordinates is opposite that of meteorological coordinates. Direction is towards the origin in meteorological coordinates, and away from the origin in engineering coordinates. An illustration of the two coordinate systems is shown in Figure 1. The two heavy arrows point in the direction the wind blows (i.e., air is moving from tail to arrowhead). Note that each arrow indicates the 180 degree direction in its respective coordinate system.

For those unfamiliar with meteorological coordinates and the expression of wind directions in meteorological degrees, the following tutorial should prove helpful.

Throughout history winds have been named for the direction they come from. Hence the cold wind blowing from the north is called the north wind and the warm wind from the south is called a south wind. Similarly, the prevailing winds in mid-latitudes which come from the west are called westerlies and the prevailing winds in the tropics which come from the east are called easterlies. In modern times azimuths and the u and v vectors have been introduced to increase precision.

Azimuth, called meteorological degrees in Figure 1, begins at north which is 0 degrees and rotates clockwise through east which is 90 degrees, south which is 180 degrees, west which is 270 degrees and back to north which is also 360 degrees.

At any point on the earth, except the poles, a local coordinate system can be used. The x-axis points east and wind velocity components in the x direction are called u. The y-axis points north and wind velocity components in the y direction are called v. The following examples explain all these conventions for an observer located in central Kansas.

If the wind is blowing from North Dakota to Texas, then the wind direction is 360 degrees which is equivalent to 0 degrees or -v and it is called a north wind or a northerly wind.

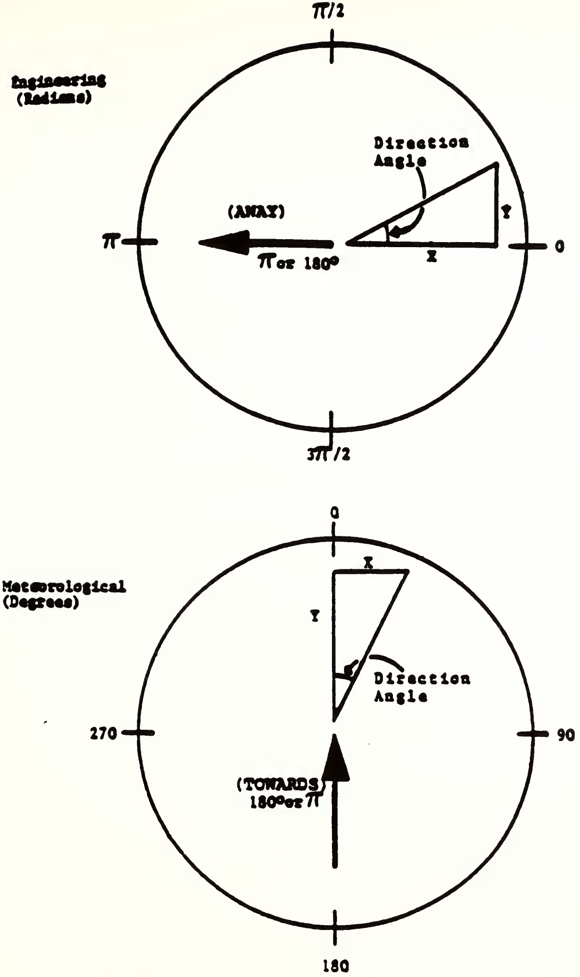


Figure 1. Illustration of the difference between Meteorological and Engineering coordinate systems.

If the wind is blowing from Richmond, VA to San Francisco, CA then the wind direction is 90 degrees which is equivalent to -u and it is called an east wind or an easterly wind.

If the wind is blowing from Texas to North Dakota, then the direction is 180 degrees which is equivalent to v and it is called a south wind or a southerly wind.

If the wind is blowing from San Francisco, CA to Richmond, VA, then the wind direction is 270 degrees which is equivalent to u and it is called a west wind or a westerly wind.

> Note: To convert from engineering to meteorological coordinates, use the following equation:
>
> $(3\pi/2) - \theta = D$
>
> where: θ is the direction in engineering coordinates and D is the direction in meteorological coordinates.
>
> If D is less than zero use:
>
> $2\pi + D = D$

4. Value

Many data elements are employed in algorithm functions as constants or operator supplied thresholds. These data elements are given values that may or may not be constant. For example, the radius of the Earth is a physical constant (6,371 kilometers) and RANGE (Cut-Off) is an operator supplied threshold that may not be constant from site to site.

5. Definition

Definitions are developed to describe a data element's function, value (including range, precision and units), and purpose. These definitions are located in the Input (2.0) and Notation (3.2.1) sections of each algorithm. Standard meteorological and mathematical terms are used whenever possible. Certain terms within definitions are unique to the NEXRAD algorithm system. These terms are referred to by their Data Dictionary names when they are included within another definition. The definition of these unique terms may then be referenced.

Examples include:

In the Input section-

RADIUS (Earth): Radius of the Earth, in kilometers.

DIAMETER (Radial): Radial diameter of a FEATURE, in kilometers.

(FEATURE may then be referenced.)

In the Notation section-

RE: RADIUS (Earth), radius of the Earth (6371 kilometers), in kilometers.

6. Category, Class, and Algorithm Number

The data base contains a large number of data elements. Category, Class, and Algorithm Number are tools that may be used to locate data elements within the data base. Category and Class are especially useful in sorting related elements according to internal functions or usage within an algorithm and to aid in producing a better definition structure within a set of related data elements.

Category, Class, and Algorithm Number explanations are listed below:

a. Category Descriptions

1. Base Data - Data that are used in estimating meteorological phenomena.

2. Data Acquisition Characteristic - Data acquisition characteristics of the radar as determined by selection of scanning modes, e.g. elevation angles.

3. Constant - Parameters that are constant at a given site during algorithm processing, but which can be changed on an adaptive basis.

4a. Computed Process Parameter - A variable data element restricted to internal use in an algorithm.

4b. Process Parameter As Strictly Input - A data element which remains constant per algorithm pass and is restricted to internal use in the algorithm.

5a. Absolute Position - The point in space given to a data element.

5b. Difference of Positions - The difference in space between two data elements.

6a. Absolute Time - The point in time that is assigned to a data element.

6b. Difference of Time - The difference in time between data elements.

7. Phenomena Quantity or Time - A physical data element that is ascribed various attributes.

8. Phenomena Attribute - A property given to a data element.

9. Indices - Subscripts used to count, or keep track of data elements.

10. Miscellaneous - Data elements not classifiable into any category.

b. Class Descriptions

A - INPUT: Parameters and data elements input from outside the algorithm stream (radar hardware, operator, etc.).

B - INTERNAL CONSTANT or VARIABLE: Parameters and data elements created within an individual algorithm to be used in an internal function or routine.

OUTPUTS: Parameters and data elements output by an algorithm to users and/or other algorithms are classified as follows:

C - External Outputs: User outputs
D - Internal Outputs: Algorithm outputs -> inputs
E - Internal/External Outputs: Combination of C and D

c. Algorithm Number

Name	No.	Name	No.
Mesocyclone Detection	2	Precipitation Products	21
*Rainfall Accumulation	3	Storm Segments	22
Storm Tracking	4	Turbulence	23
Storm Centroids	5	Divergence Detection	24
Vertically-Integrated	6	*Layer Composite	25
Velocity Azimuth Display	7	TVS Detection	26
Storm Position Forecast	8	Sectorized Uniform Wind	27
Storm Structure	9	*Cross-Correlation Tracking	28
*Shear	10	Gust Front Detection	29
Transverse Wind	11	Flash Flood Precipitation Projection	30
Hail	12	Flash Flood Potential Assessment	31
Echo Tops	13	*Flash Flood Precipitation Products	32
*Weak Echo Region	14	Combined Shear	33
Severe Weather Probability	15	Cross-Correlation Tracking	34
Modified Velocity Volume Processing	16		
Precipitation Preprocessing	17		
Precipitation Rate	18		
Precipitation Accumulation	19		
Precipitation Adjustment	20		

Note: This list will be expanded as new algorithms are developed.

*Algorithms 3, 10, 14, 25, 28 and 32 are no longer NEXRAD system documents.

APPENDIX A

NEXRAD Algorithm

Data Dictionary

(sorted alphabetically)

KEY FOR READING
THE NEXRAD ALGORITHM DATA DICTIONARY
(sorted alphabetically)

NAME	SYMBOL	UNITS

DEFINITION:

ALGORITHM REFERENCE NUMBERS

NEXRAD: Algorithm Data Dictionary

(sorted alphabetically)

NAME	SYMBOL	UNITS
2-D FEATURE TYPE	TDFT	N/A

DEF: Assigns an unique value to indicate that a 2-D FEATURE characterizes a MESOCYCLONE and another if it does not.

ALGO REF NOs: 2

NAME	SYMBOL	UNITS
ABSOLUTE DIFFERENCE(#1)	AD1	km**2

DEF: The ABSOLUTE DIFFERENCE between the AREA(Complete Precipitation) and the reference AREA(Inner Precipitation), in km**2.

ALGO REF NOs: 18

NAME	SYMBOL	UNITS
ABSOLUTE DIFFERENCE(#2)	AD2	km**2

DEF: The ABSOLUTE DIFFERENCE between the AREA(Inner Precipitation) and the reference AREA(Complete precipitation, in km**2.

ALGO REF NOs: 18

NAME	SYMBOL	UNITS
ABSOLUTE DIFFERENCE(Maximum)	AD	km**2

DEF: The maximum ABSOLUTE DIFFERENCE in echo area allowed in order to pass the time continuity test, in km**2.

ALGO REF NOs: 18

ACCUMULATION SCAN(Hourly) ASH dBA

DEF: The hourly radar precipitation accumulation data for an hourly running period or clock hour on a 1 degree by 2 kilometer polar grid from 1 to 230 kilometers, in dBA. A precision of at least 0.5 dBA and a dynamic range of at least -18 to 32 dBA are required. Includes the beginning TIME(Accumulation) and ending TIME(Accumulation).
-adjusted

ALGO REF NOs: 19,20,21

ACCUMULATION SCAN(Period) ASP dBA

DEF: The interpolated or extrapolated period precipitation accumulation data on a 1 degree by 2 km polar grid from 1 to 230 km. A precision of at least 0.5 dBA and a dynamic range of at least -29 to 26 dBA are required.
-forward, backward extrapolated
-current, previous average TIME
-interpolated

ALGO REF NOs: 19

ACCUMULATION SCAN(Scan-to-Scan) ASS dBA

DEF: The total scan-to-scan accumulation data on a 1 degree by 2 kilometer polar grid from 1 to 230 kilometers for the period from the previous time to the current time, in dBA.
A precision of at least 0.5 dBA and a dynamic range of at least -29 to 26 dBA are required. Includes the previous average TIME(Scan) and current average TIME(Scan).
-adjusted

ALGO REF NOs: 19,20,21,30

ACCUMULATION(Hourly) AH dBA

DEF: The interpolated hourly accumulation using the eight neighboring sample volume accumulation values, in dBA. Precise to 0.5 dBA.
-interpolated

ALGO REF NOs: 19

NAME SYMBOL UNITS

ACCUMULATION(Rainfall) ACR mm

DEF: The rainfall accumulation for a sample volume within a particular ACCUMULATION SCAN(Period), in millimeters. A precision of 0.01 millimeters and a dynamic range of 0 to 398 millimeters are required.

ALGO REF NOs: 19

ACCUMULATION(Zero Extrapolated) AZE dBA

DEF: The zero level for an extrapolated ACCUMULATION SCAN (Period), in dBA. A precision of at least 0.5 dBA and dynamic range of at least -29 to 26 dBA are required.

ALGO REF NOs: 19

ACCUMULATION(Zero Hourly) AZH dBA

DEF: The hourly precipitation accumulation considered to be zero (-18), in dBA. Precise to 0.5 dBA.

ALGO REF NOs: 19,20,21

ACCUMULATION(Zero Interpolated) AZI dBA

DEF: The zero level for an interpolated ACCUMULATION SCAN (Period), in dBA. A precision of at least 0.5 dBA and a dynamic range of at least -29 to 26 dBA are required.

ALGO REF NOs: 19

ACCUMULATION(Zero Level) AZL dBA

DEF: The zero level for the ACCUMULATION SCAN(Scan-to-Scan), in dBA. A precision of at least 0.5 dBA and a range of at least -29 to 26 dBA are required.

ALGO REF NOs: 20

NAME SYMBOL UNITS

ACCUMULATION(Zero Period) AZP dBA

DEF: The zero level for a particular ACCUMULATION SCAN (Period), in dBA. A precision of at least 0.5 dBA and a dynamic range of -29 dBA to 26 dBA are required.

ALGO REF NOs: 19

ACCUMULATION(Zero Value) AZV mm

DEF: The zero value for scan-to-scan accumulation data, in mm. A precision of at least 0.1 mm and a dynamic range from 0 to 1 mm are required.

ALGO REF NOs: 21

ADJACENCY ADJ unitless

DEF: The number of adjacent azimuths required to define a STORM COMPONENT.
-minimum

ALGO REF NOs: 5

ALLOWABLE ERROR AER km/hr

DEF: The maximum error in the track of a STORM allowed during the ERROR INTERVAL, in kilometers.

ALGO REF NOs: 8

ALTITUDE ALT km

DEF: The height above sea level, in kilometers.

ALGO REF NOs: 7

NAME SYMBOL UNITS

ANGLE(Between Overhang and Direction) ANG radians

DEF: The horizontal angle formed by a line from the centroid of the STORM COMPONENT of a STORM at a particular ELEVATION and the centroid of the STORM COMPONENT of the same storm at lowest ELEVATION to a line that is parallel to the direction of the storm's movement, in radians.

ALGO REF NOs: 12

AREA AFE km**2

DEF: The area of a FEATURE, in km**2.

ALGO REF NOs: 29

AREA MEASURED(Feature) AMF km**2

DEF: The measured area of the divergence FEATURE (the summation of PATTERN VECTOR areas), in km**2.

ALGO REF NOs: 24

AREA(Complete Precipitation) ACP km**2

DEF: The precipitation echo area included within a 230 km radius from the radar, in km**2.
-reference
-from the last good scan

ALGO REF NOs: 18

AREA(Echo) AE km**2

DEF: The area of precipitation echoes in low tilt sectors and between the inner and outer RANGEs(Tilt Test) which must be exceeded in order to do the tilt test, in km**2.
-minimum

ALGO REF NOs: 17

NAME SYMBOL UNITS

AREA(Feature) AF km**2

DEF: The estimated area of the divergence FEATURE, in km**2.

ALGO REF NOs: 24

AREA(Inner Precipitation) AIP km**2

DEF: The precipitation echo area included within the RADIUS (Inner) from the radar, in km**2.
-reference
-from the last good scan

ALGO REF NOs: 18

AREA(Lowest Elevation Echo) ALE km**2

DEF: Echo area including those SAMPLE VOLUMEs with a reflectivity factor greater than the REFLECTIVITY(Tilt Test) from the lowest elevation sectors and between the inner and outer RANGEs(Tilt Test), in km**2.

ALGO REF NOs: 17

AREA(Percent Reduction) APR percent

DEF: The percentage echo area from the lowest elevation sectors and between the inner and outer RANGEs(Tilt Test) which is eliminated by going to the second lowest elevation.
-maximum

ALGO REF NOs: 17

AREA(Sample Volume) ASV km**2

DEF: The area of a particular SAMPLE VOLUME in the RATE SCAN to the nearest 0.01 km**2, in km**2.

ALGO REF NOs: 17,18

NAME	SYMBOL	UNITS
AREA(Second Elevation Echo)	ASL	km**2

DEF: The echo area which satisfies the requirements of AREA (Lowest Elevation Echo) at the lowest elevation but not at the second lowest elevation, in km**2.

ALGO REF NOs: 17

NAME	SYMBOL	UNITS
AREA(Storm Component)	A	km**2

DEF: Area of a STORM COMPONENT at a particular ELEVATION, in km**2.
-sample volume area
-particular STORM

ALGO REF NOs: 5,9,12

NAME	SYMBOL	UNITS
AREA(Surface Change)	ASC	km

DEF: The rate of change of AREA(Surface) with respect to height, in km**2/km or kilometers.

ALGO REF NOs: 7

NAME	SYMBOL	UNITS
AREA(Surface)	AS	km**2

DEF: The surface area in the plane above the radar bounded by the VAD analysis range, in km**2.

ALGO REF NOs: 7

NAME	SYMBOL	UNITS
AREA(Time Continuity)	ATC	km**2

DEF: Precipitation area to allow a time continuity test on volumetric precipitation rates, in km**2.
-minimum

ALGO REF NOs: 18

NAME SYMBOL UNITS

ARRAY PRODUCT(Digital Precipitation) APDP dBA

DEF: The hourly running total or clock hour total on a 1/40th LFM Grid out to 230 km in a 100 level computer compatible format, including appropriate supplemental data.

ALGO REF NOs: 21

ASYMPTOTE(Quasi) ASY km**2/3

DEF: The quasi-asymptotic value, at a range of 220 kilometers, of the curve that estimates the SPECTRUM WIDTH (Normalized Variance), in km**2/3.

ALGO REF NOs: 23

AZIMUTH AZ radians

DEF: Azimuthal position, in radians.
-beginning-pattern vector
-ending-pattern vector
-feature, beginning-feature
-ending-feature
-minimum, maximum
-center-feature
-begin interpolation
-end interpolation

ALGO REF NOs: 2,5-7,11,13,16,18,22,24,26,27,29,33

AZIMUTH LIMITS AZA1-AZA4 radians

DEF: Azimuth angles to the vertices of the cartesian grid, with the radar as the origin.

ALGO REF NOs: 33

NAME SYMBOL UNITS

AZIMUTH MAXIMUM AZIMAX radians

DEF: The largest azimuth found within a FEATURE, in radians.

ALGO REF NOs: 2

AZIMUTH MINIMUM AZIMIN radians

DEF: The smallest azimuth found within a FEATURE, in radians.

ALGO REF NOs: 2

AZIMUTH POSITION AZPO azimuth

DEF: The position of a point in a FEATURE, in azimuth.

ALGO REF NOs: 29

AZIMUTH RANGE(SLANT) ARS km

DEF: The average slant range for the azimuth of a STORM COMPONENT, in kilometers.
-beginning
-ending

ALGO REF NOs: 5

AZIMUTH(Delta) AZDE radians

DEF: The azimuthal increment, in radians.

ALGO REF NOs: 5

AZIMUTH(Filtered Velocities) AFL radians

DEF: A set of AZIMUTHS for which VELOCITY FILTERED will be calculated. This is currently specified as groups of 3 adjacent AZIMUTHS centered every 10 degrees around an AZIMUTH sweep, beginning at 0 degrees (in radians).
-before
-after

ALGO REF NOs: 27

NAME	SYMBOL	UNITS
AZIMUTH(Maximum Velocity)	AMV	radians

DEF: The azimuth of a maximum VELOCITY(Doppler Range) within a FEATURE, in radians.

ALGO REF NOs: 26

NAME	SYMBOL	UNITS
AZIMUTH(Minimum Velocity)	ANV	radians

DEF: The azimuth of a minimum VELOCITY(Doppler Range) within a FEATURE, in radians.

ALGO REF NOs: 26

NAME	SYMBOL	UNITS
BEAM WIDTH	BW	radians

DEF: The angular width of the radar beam between the half-power points, in radians (.017).

ALGO REF NOs: 6,23

NAME	SYMBOL	UNITS
BEGIN(Time)	TBi	hr

DEF: Time of start of precipitation at the i-th BOX(1/40th LFM Grid) to the nearest 1/1200 hour.

ALGO REF NOs: 30

NAME	SYMBOL	UNITS
BEST X-POSITION	BXP	km

DEF: An X-position based on either the SPEED(Mean) or previous SPEED(Storm), in kilometers.

ALGO REF NOs: 4

NAME	SYMBOL	UNITS
BEST X-SPEED	BXS	km/hr

DEF: The SPEED in the X-direction, in km/hr.

ALGO REF NOs: 4

BEST Y-POSITION	BYP	km

DEF: A Y-position based on either the SPEED(Mean) or previous SPEED(Storm), in kilometers.

ALGO REF NOs: 4

BEST Y-SPEED	BYS	km/hr

DEF: The SPEED in the Y-direction, in km/hr.

ALGO REF NOs: 4

BIAS	B	unitless

DEF: The multiplicative factor that adjusts for the radar bias when compared to surface precipitation measurements (presumably 1).
-previous, current, forecasted, reset (long term mean)

ALGO REF NOs: 20,30

BOX	BOX	N/A

DEF: A window comprised of an equal number of SAMPLE VOLUMEs in range and azimuth defining the size of the area to be correlated.
-BOX(1)
-BOX(2)

ALGO REF NOs: 11

BOX OVERLAP TBO percent

DEF: Percent overlap desired from the initial box in the first scan to the next box in the second scan.

ALGO REF NOs: 11

BOX(1/4 LFM Grid) BLG N/A

DEF: Rectangular grid box which is 1/4th of the Limited Fine Mesh (LFM) grid used by the National Weather Service. Consists of a file specifying the RATE SCAN data sample volumes whose centers fall within each of the 1/4th LFM grid boxes.

ALGO REF NOs: 18

BOX(1/40 LFM Grid) BLM N/A

DEF: Rectangular grid box centered on 1/40th LFM grid points. At 60 degrees N the mesh length is 4.7625 km. Specifies the scan's sample volumes whose centers fall within each grid box. If none, the sample volume whose center is closest to the center of the grid box is specified. Grid boxes whose centers are more than 230 km from the radar are not assigned any sample volumes.

ALGO REF NOs: 21,30

BOX(2 km X 2 km Grid) BX N/A

DEF: These are square grid boxes which are 2 km on a side and cover ranges from 0 to 230 km. Specifies the 1 degree by 2 km accumulation scan sample volumes whose centers fall within each grid box. If none, the sample volume whose center is closest to the center of the grid box is specified. Grid boxes whose centers are more than 230 km from the radar are not assigned any sample volumes.

ALGO REF NOs: 21

BOX(4 km X 4 km Grid) BX4 N/A

DEF: Square grid boxes which are 4 km on a side and cover ranges from 0 to 230 km.

ALGO REF NOs: 6,13

BOX(SWP) BSP km**2

DEF: An area surrounding a VIL grid box, in km**2.

ALGO REF NOs: 15

CATEGORIES C unitless

DEF: Categorized effective reflectivity factor data for each SAMPLE VOLUME.

ALGO REF NOs: 6,13

CATEGORY(Precipitation) CPRE N/A

DEF: The precipitation category currently in effect.
Category Meaning:
0 = No precipitation detected
during the past hour
1 = Significant precipitation detected
during the past hour
2 = Light precipitation detected
during the past hour

ALGO REF NOs: 17,18,19,20,21

CENTROID DISTANCE CED km

DEF: The distance or radius of a STORM COMPONENT, in kilometers.

ALGO REF NOs: 5

NAME **SYMBOL** **UNITS**

COEFFICIENT(Correlation Azimuth, #1) CA1 unitless

DEF: Coefficient #1 of a second order-equation for the correlation coefficient as a function of azimuth.

ALGO REF NOs: 11

COEFFICIENT(Correlation Azimuth, #2) CA2 1/radians

DEF: Coefficient #2 of a second order-equation for the correlation coefficient as a function of azimuth, in 1/radians.

ALGO REF NOs: 11

COEFFICIENT(Correlation Azimuth, #3) CA3 1/radians**2

DEF: Coefficient #3 of a second order-equation for the correlation coefficient as a function of azimuth, in 1/radians**2.

ALGO REF NOs: 11

COEFFICIENT(Correlation Range, #1) CR1 unitless

DEF: Coefficient #1 of a second-order equation for the correlation coefficient as a function of range.

ALGO REF NOs: 11

COEFFICIENT(Correlation Range, #2) CR2 1/km

DEF: Coefficient #2 of a second-order equation for the correlation coefficient as a function of range, in 1/km.

ALGO REF NOs: 11

COEFFICIENT(Correlation Range, #3) CR3 1/km**2

DEF: Coefficient #3 of a second-order equation for the correlation coefficient as a function of range, in 1/km**2.

ALGO REF NOs: 11

COEFFICIENT(Fourier, #1) CF1 km/hr

DEF: The Fourier series coefficient #1 that allows for the best possible approximation of a function, in km/hr.

ALGO REF NOs: 7

COEFFICIENT(Fourier, #2) CF2 km/hr

DEF: The Fourier series coefficient #2 that allows for the best possible approximation of a function, in km/hr.

ALGO REF NOs: 7

COEFFICIENT(Fourier, #3) CF3 km/hr

DEF: The Fourier series coefficient #3 that allows for the best possible approximation of a function, in km/hr.

ALGO REF NOs: 7

COEFFICIENT(Multiplicative Z-R) CZM N/A

DEF: Multiplicative coefficient in the Z-R conversion equation (approximately 300).

ALGO REF NOs: 18

NAME	SYMBOL	UNITS
COEFFICIENT(Range Effect)	C01-C03	Unitless

DEF: Three coefficients used to specify the range effect correction function.

ALGO REF NOs: 18

NAME	SYMBOL	UNITS
COEFFICIENT(Z-R Power)	CZP	unitless

DEF: Power coefficient in the Z-R conversion equation, (approximately 1.4).

ALGO REF NOs: 18

NAME	SYMBOL	UNITS
COLUMN DISPLACEMENT(Correlation Maximum)	DPCM	correl. pixels

DEF: Column displacement of the correlation box in LAYER (Previous) yielding the maximum value of CORRELATION (Box Displacement), units of correlation pixels.

ALGO REF NOs: 34

NAME	SYMBOL	UNITS
COLUMN DISPLACEMENT(Interpolated)	DPCI	Correl. pixels

DEF: Quadratic estimate of peak location in correlation surface sampled in FIELD(Correlation) in the column dimension, units of correlation pixels.

ALGO REF NOs: 34

NAME	SYMBOL	UNITS
COLUMN VELOCITY	VELC	km/hr

DEF: Correlation-based estimate of the velocity of a correlation box in the column dimension of LAYER (Previous), units of km/hr.

ALGO REF NOs: 34

NAME	SYMBOL	UNITS
COMBINED SHEAR	COSH	1/hr

DEF: Combined shear as computed from the mean radial shear and the mean azimuthal shear, in 1/hr.

ALGO REF NOs: 33

CONFIDENCE FACTOR	CFA	percent

DEF: The level of confidence in the prediction of hail for a particular storm, in percent.

ALGO REF NOs: 12

CORRELATION(Box Displacement)	COC	unitless

DEF: The coefficient of correlation between the thresholded data of a correlation box in LAYER (Previous) and an equally-sized array of data in LAYER (Current).

ALGO REF NOs: 34

CORRELATION(Coefficient)	CC	unitless

DEF: A number representing the degree to which two variables are dependent upon each other.
-optimum

ALGO REF NOs: 11

CORRELATION(Distance)	CD	km

DEF: Defines the distance used (between centroids) to determine if a current storm is the same as one of the storms identified earlier, in kilometers.

ALGO REF NOs: 4

NAME	SYMBOL	UNITS
CORRELATION(Parameters)	CCP	N/A

DEF: A normalized procedure which allows the residuals to be directly compared from one scan to the next to derive a single parameter residual decay.

ALGO REF NOs: 30

CORRELATION(Speed)	CS	km/hr

DEF: Speed used to compute the CORRELATION(Distance), in km/hr.

ALGO REF NOs: 4

CORRELATION(Table)	CT	N/A

DEF: A data set used to keep track of the positions of correlated STORMs.

ALGO REF NOs: 4,8

COUNT FILTER(Azimuthal)	CFLA	N/A

DEF: Count of the number of (mean SHEAR(Azimuthal)) values used in filter for current point being filtered. This value will always be less than or equal to NUMBER (Filter).

ALGO REF NOs: 33

COUNT FILTER(Radial)	CFLR	N/A

DEF: Count of the number of (mean SHEAR(Radial)) values used in filter for current point being filtered. This value will always be less than or equal to NUMBER(Filter).

ALGO REF NOs: 33

NAME SYMBOL UNITS

COUNTER((Storm) Sample Values) CSS N/A

DEF: Values computed for the determination of the mean precipitation of a COUNTER(Storm) and its standard deviation.

ALGO REF NOs: 30

COUNTER(Autocorrelation) NA unitless

DEF: The number of sample values available to compute autocorrelations.

ALGO REF NOs: 30

COUNTER(Highest Storm) NIH unitless

DEF: Highest COUNTER(Storm) needed for the projection.

ALGO REF NOs: 30

COUNTER(Storm) NI unitless

DEF: The number of time steps since the start of precipitation at LOCboxi.
-largest, maximum
-temporary
-i-th BOX (1/40th LFM grid)

ALGO REF NOs: 30

DATA(Bad) DTB unitless

DEF: A value which indicates missing or poor quality data assigned to velocity data to prevent processing by the algorithm.

ALGO REF NOs: 27

NAME SYMBOL UNITS

DEFAULT(Direction) DDI radians

DEF: A default storm direction value used if directions are not known, in radians.

ALGO REF NOs: 12

DEFAULT(Speed) DSD km/hr

DEF: A default storm speed value used if speeds are not known, in km/hr.

ALGO REF NOs: 12

DEFORMATION(Horizontal) DEF 1/hr

DEF: The horizontal deformation of the wind field, in 1/hr.

ALGO REF NOs: 16

DENSITY(Atmospheric Gradient) DRHO# kg/km**4

DEF: A set of density gradient values at each altitude, in kg/km**4.

ALGO REF NOs: 7

DENSITY(Atmospheric) RHO# kg/km**3

DEF: A set of density values for each altitude, in kg/km**3.

ALGO REF NOs: 7

DEPTH(Beam) DB km

DEF: The depth of the radar beam as a function of range for each grid box, in kilometers.

ALGO REF NOs: 6

NAME SYMBOL UNITS

DERIVATIVE OF u(In X-Direction) DUX 1/hr

DEF: Derivative of the u-component of wind about the X-axis, in 1/hr.

ALGO REF NOs: 16

DERIVATIVE OF u(In Y-Direction) DUY 1/hr

DEF: Derivative of the u-component of wind about the Y-axis, in 1/hr.

ALGO REF NOs: 16

DERIVATIVE OF u(In Z-Direction) DUZ 1/hr

DEF: Derivative of the u-component of wind about the Z-axis, in 1/hr.

ALGO REF NOs: 16

DERIVATIVE OF v(In X-Direction) DVX 1/hr

DEF: Derivative of the v-component of wind about the x-axis, in 1/hr.

ALGO REF NOs: 16

DERIVATIVE OF v(In Y-Direction) DVY 1/hr

DEF: Derivative of the v-component of wind about the Y-axis, in 1/hr.

ALGO REF NOs: 16

DERIVATIVE OF v(In Z-Direction) DVZ 1/hr

DEF: Derivative of the v-component of wind about the Z-axis, in 1/hr.

ALGO REF NOs: 16

NAME SYMBOL UNITS

DERIVATIVE(Azimuthal) VT (km/hr)(1/rad.)

DEF: The azimuthal derivative of the Doppler estimated radar velocity (transverse component), in (km/hr)(1/radians).

ALGO REF NOs: 27

DIAMETER(Azimuthal) DAA km

DEF: Azimuthal diameter of a FEATURE, in kilometers.

ALGO REF NOs: 2

DIAMETER(Momentum Azimuthal) DMA km

DEF: The momentum weighted azimuthal diameter of a FEATURE, in kilometers.

ALGO REF NOs: 2

DIAMETER(Radial) DAR km

DEF: Radial diameter of a FEATURE, in kilometers.

ALGO REF NOs: 2

DIFFERENCE(Azimuthal) DA N/A

DEF: Differences in average VELOCITY(Doppler) computed between adjacent azimuths and at constant range.

ALGO REF NOs: 33

DIFFERENCE(Best Position) BPD km

DEF: The distance between the best position point as computed by the SPEED(Mean) and direction or STORM(Speed) and direction and the current position of the STORM centroid, in kilometers.

ALGO REF NOs: 4

NAME	SYMBOL	UNITS
DIFFERENCE(Between Feature Centers)	DIF	km

DEF: The horizontal distance between FEATURE CENTER POSITIONs (at adjacent elevation angles), in kilometers.

ALGO REF NOs: 2

NAME	SYMBOL	UNITS
DIFFERENCE(Radial)	DR	N/A

DEF: Radial differences in average VELOCITY(Doppler) computed between sample volumes spaced NUMBER(Sample Volumes) apart and at constant azimuth.

ALGO REF NOs: 33

NAME	SYMBOL	UNITS
DIRECTION(Best Position)	DPB	radians

DEF: The direction towards which a STORM is moving, in radians.

ALGO REF NOs: 4

NAME	SYMBOL	UNITS
DIRECTION(Limit)	DLM	radians

DEF: The maximum deviation from the DIRECTION(Best Position) that a STORM is allowed in order to be considered as the STORM at a previous time (PI#/2), in radians.

ALGO REF NOs: 4

NAME	SYMBOL	UNITS
DIRECTION(Mean)	DMN	radians

DEF: The direction towards which a STORM is moving. This is either obtained from the average of the DIRECTION(Storm) or the operation input, in radians.

ALGO REF NOs: 4

NAME	SYMBOL	UNITS
DIRECTION(Minus)	DM	radians

DEF: The DIRECTION(Best Position) minus the DIRECTION (Limit), in radians.

ALGO REF NOs: 4

NAME	SYMBOL	UNITS
DIRECTION(Plus)	DP	radians

DEF: The DIRECTION(Best Position) plus the DIRECTION(Limit), in radians.

ALGO REF NOs: 4

NAME	SYMBOL	UNITS
DIRECTION(Storm Position)	DSP	radians

DEF: The direction between centroids at the current time and centroids at the previous time, in radians.

ALGO REF NOs: 4

NAME	SYMBOL	UNITS
DIRECTION(Storm)	DS	radians

DEF: Direction from which a STORM is moving, in radians.
-nth
-average
-(In Algo #12), NOTE: If the direction is not determined by the STORM POSITION FORECAST[008] algorithm, then its value is set as being unknown:

ALGO REF NOs: 8,9,12

NAME	SYMBOL	UNITS
DIRECTION(Wind)	DW	radians

DEF: The horizontal direction from which the wind is flowing, in radians.
-average

ALGO REF NOs: 7,11

NAME SYMBOL UNITS

DISTANCE MATRIX DISM km

DEF: The distance from each gage to every other gage, in kilometers.

ALGO REF NOs: 20

DISTANCE SQUARED(Box) DSQB km**2

DEF: The distance, squared, from the correlation box with undetermined velocities in Section 6.0 of the algorithm to a correlation box whose velocities were computed in Section 5.0, units of km**2.

ALGO REF NOs: 34

DISTANCE(Between Centroids) DC km

DEF: The horizontal distance between the centroid of the STORM COMPONENT of a STORM at the lowest ELEVATION and the centroid of the STORM COMPONENT of the same STORM at some higher ELEVATION, in kilometers.

ALGO REF NOs: 12

DISTANCE(Between Gages) DG km

DEF: The distance between gages in the VECTOR (Gage Observation), in kilometers. Precise to 0.1 km.

ALGO REF NOs: 20

DISTANCE(Earth Center) DEC km

DEF: The distance from the Earth center, in kilometers.

ALGO REF NOs: 7

NAME SYMBOL UNITS

DISTANCE(Maximum Lag) DML correl. pixels

DEF: The displacement of an object moving at SPEED(Storm Limit) for a time interval equal to that between LAYER (Previous) and LAYER(Current), units of correlation pixels.

ALGO REF NOs: 34

DISTANCE(Storm Top and Mid Level) DTM km

DEF: The horizontal distance between the centroid of a STORM COMPONENT of a STORM at a midlevel altitude (5 to 12 kilometers) and the centroid of the STORM COMPONENT of the same STORM at the highest ELEVATION, in kilometers.

ALGO REF NOs: 12

DIVERGENCE(Horizontal) DIV 1/hr

DEF: Horizontal divergence, in 1/hr.

ALGO REF NOs: 7

DIVERGENCE(Radial) DVR 1/hr

DEF: The radial divergence in a divergence FEATURE, in 1/hr.
-maximum
-average

ALGO REF NOs: 24

DOMAIN(Resolution) DOR km

DEF: Grid point spacing for the Cartesian grid, in km (0.5-4.0).

ALGO REF NOs: 33

NAME SYMBOL UNITS

DOMAIN(X Minimum) DXM km

DEF: The lower left X(W-E) coordinate relative to the radar for the rectangular Cartesian grid for the interpolated shears, in km.

ALGO REF NOs: 33

DOMAIN(X Size) DXS km

DEF: Length of the (W-E) side of the Cartesian grid box, in km (230).
NOTE: The box is centered on the radar.

ALGO REF NOs: 33

DOMAIN(Y Minimum) DYM km

DEF: The lower left Y(S-N) coordinate relative to the radar for the rectangular Cartesian grid for the interpolated shears, in km.

ALGO REF NOs: 33

DOMAIN(Y Size) DYS km

DEF: Length of the (S-N) side of the Cartesian grid box, in km (230).
NOTE: The box is centered on the radar.

ALGO REF NOs: 33

DURATION(Incremental Report Overlap) DIO hr

DEF: The duration of the portion of a particular incremental gage report that overlaps the hourly accumulation period, in hours to the nearest 1/1200 hour.

ALGO REF NOs: 20

NAME	SYMBOL	UNITS
ELEVATION	PHI#	radians

DEF: Elevation angle, in radians.
-effective

ALGO REF NOs: 2,5-7,9,11-13,16,17,22,24,26,27,29,33

NAME	SYMBOL	UNITS
ELEVATION/RANGE/AZIMUTH BOUNDARIES	ERB	radians/km/deg

DEF: The minimum and maximum range and azimuth sector boundaries and ELEVATIONs (4) for which reflectivity factor data are used to build the hybrid scan. The values used will vary from site to site, depending on local terrain, clutter conditions and elevation angles used.

ALGO REF NOs: 17

NAME	SYMBOL	UNITS
ERROR INTERVAL	EI	hr

DEF: The amount of time upon which the ALLOWABLE ERROR was based, in hours.

ALGO REF NOs: 8

NAME	SYMBOL	UNITS
ERROR VARIANCE	EV	mm**2

DEF: The observed error variance for the i-th BOX(1/40th LFM Grid) (in mm**2).
-number of samples
-sum grid box observed
-grid box observed

ALGO REF NOs: 30,31

NAME	SYMBOL	UNITS
ERROR(Proportion Factor)	EPF	N/A

DEF: Ratio of presumed observational error variance of precipitation rates to local (5 x 5 grids) variance of precipitation rates themselves.

ALGO REF NOs: 30

NAME SYMBOL UNITS

FEATURE FEA N/A

DEF: A set of PATTERN VECTORs which have passed spatial proximity.

ALGO REF NOs: 2,24,26

FEATURE CENTER POSITION FCP N/A

DEF: The FEATURE center position in range, elevation and azimuth.
-azimuth angle, beginning, ending

ALGO REF NOs: 2,24

FEATURE CENTER(Azimuth) FCAZ azimuth

DEF: FEATURE CENTER(Azimuth), the FEATURE center position, in azimuth.

ALGO REF NOs: 29

FEATURE CENTER(Slant Range) FCRS range

DEF: The FEATURE center position, in range.

ALGO REF NOs: 29

FEATURE EXTREMA FEX N/A

DEF: A set of four parameters (beginning RANGE(Slant-Feature), ending RANGE(Slant-Feature), beginning feature AZIMUTH, and ending feature AZIMUTH). These are the maximum and minimum AZIMUTHs of its PATTERN VECTOR LIST, and the maximum and minimum ranges from the PATTERN VECTOR LIST.

ALGO REF NOs: 2,26

NAME SYMBOL UNITS

FEATURE FLUX FF km**2/hr

DEF: The flux of a FEATURE, in km**2/hr.
-average
-maximum

ALGO REF NOs: 29

FEATURE(Convergence) FEAC N/A

DEF: A set of PATTERN VECTORs (Radial) in close spatial proximity.

ALGO REF NOs: 29

FIELD(Correlations) FLC N/A

DEF: An array of the same dimensions, spatial resolution and orientation as the correlation box subarrays of LAYER(Previous), containing the field of CORRELATION (Box Displacement) computed for this correlation box.

ALGO REF NOs: 34

FIT FIT km/hr

DEF: The Doppler velocity value at a given azimuth angle on the Fourier least squares fitted curve, in km/hr.

ALGO REF NOs: 7

FIT TESTS FT N/A

DEF: The number of times the fit test procedure is to be run.

ALGO REF NOs: 7

NAME	SYMBOL	UNITS

FLAG VALUE FLV N/A

DEF: Default value for filtered SHEAR(Radial-RSA), filtered SHEAR(Azimuthal) and COMBINED SHEAR.

ALGO REF NOs: 33

FLAG(Bad) FB N/A

DEF: When set, designates a precipitation rate scan as including bad data and removes it from further processing.

ALGO REF NOs: 18

FLAG(Missing Data) FMD N/A

DEF: A flag indicating missing incremental gage report data during the hourly accumulation period.

ALGO REF NOs: 20

FLAG(No Hourly Accumulation) FNA N/A

DEF: A set or cleared flag indicating, if set, that no hourly accumulations were computed for the hour ending at the current ending TIME(Accumulation).

ALGO REF NOs: 19,20,21

FLAG(No Projection) FNP N/A

DEF: A set or cleared flag for each average TIME(Scan) indicating, if set, that no projection is possible because of insufficient data or the average TIME(Scan) minus TIME(Last Precipitation Detected) is greater than TIME(Reset).

ALGO REF NOs: 30,31

FLAG(Zero Hourly Accumulation) FHA N/A

DEF: A set or cleared flag indicating, if set, that all current ACCUMULATION SCAN(Hourly) values can be assumed to be equal to ACCUMULATION(Zero Hourly).

ALGO REF NOs: 19,20,21

FLAG(Zero Hybrid) FZH N/A

DEF: A set or cleared flag indicating, if set, that no precipitation exists in the current scan.

ALGO REF NOs: 17,18

FLAG(Zero Rate) FZR N/A

DEF: A set or cleared flag for each average TIME(Scan) indicating, if set, that all precipitation rate values can be assumed to be equal to RATE(Zero Precipitation).

ALGO REF NOs: 18,19,30

FLAG(Zero Scan-To-Scan) FZS N/A

DEF: A set or cleared flag indicating, if set, that all current ACCUMULATION SCAN(Scan-to-Scan) values can be assumed to be equal to ACCUMULATION(Zero Interpolated).

ALGO REF NOs: 19,20,21,30

FLASH FLOOD PROBABILITY FFP percent

DEF: The observed flash flood probability for the i-th BOX (1/40th LFM Grid) for guidance value durations of 1, 3, and 6 hours (in percent).
-maximum projected
-observed
-zonal maximum total storm
-projected
-maximum observed
-zonal maximum observed

ALGO REF NOs: 31

NAME SYMBOL UNITS

FLASH FLOOD(Guidance Table) FFG N/A

DEF: A table composed of three columns: (1) FLASH FLOOD (Zone) (2) FLASH FLOOD (Guidance Value) (3) FLASH FLOOD (Guidance Duration). Each entry in the table gives a rainfall accumulation in mm (the Guidance Value) which will cause flash flooding within a particular geographic area (the Zone) if it occurs over a particular duration in hours (the Guidance Duration). The FLASH FLOOD (Guidance Table) is produced at the River Forecast Centers (currently once a day) and communicated to ..

ALGO REF NOs: 31

FLASH FLOOD(Guidance Table)(Con't) FFG(Con't) N/A

DEF: ..the RPG using the existing rain gage acquisition port.

ALGO REF NOs: 31

FLASH FLOOD(Guidance Value) FFGV inches

DEF: The Flash Flood Guidance Value is the amount of rainfall over a specified duration required to produce flooding (in inches).

ALGO REF NOs: 31

FLUX F km**2/hr

DEF: The air mass flux (per unit mass) associated with divergence, in km**2/hr.

-average

-maximum

ALGO REF NOs: 24

NAME SYMBOL UNITS

FLUX(Convergence) FVVC km**2/hr

DEF: The flux of a PATTERN VECTOR(Radial), in km**2/hr.

ALGO REF NOs: 29

FORECAST ERROR FE km

DEF: The departure of the current STORM position from the position forecasted for that STORM of the previous time, in km.
-mean

ALGO REF NOs: 8

FORECAST INTERVAL FI hr

DEF: A set of time intervals for which centroid positions may be projected into the future, in hours.

ALGO REF NOs: 8

FREQUENCY(Cutoff) FCO unitless

DEF: The cutoff frequency of the filter (0.15 cycles per data interval recommended by the author).

ALGO REF NOs: 27

GAGE ACCUMULATION(Estimated Hourly) GA mm

DEF: The estimated hourly accumulation in mm at a gage for the one hour period ending at TAend.
-incremental
-accumulator

ALGO REF NOs: 20

NAME	SYMBOL	UNITS
GAGE REPORTS(Accumulator)	GRA	mm, abs. time

DEF: Reported values of accumulation (mm) at each gage and time of occurrence.

ALGO REF NOs: 20

NAME	SYMBOL	UNITS
GAGE REPORTS(Incremental)	GRI	mm,hr,abs. time

DEF: Reported values of incremental accumulation (mm), increment duration and time of occurrence.

ALGO REF NOs: 20

NAME	SYMBOL	UNITS
GAGE-RADAR DIFFERENCE	GR	mm

DEF: The difference in accumulation between a GAGE ACCUMULATION (Estimated Hourly) and the corresponding radar accumulation, in millimeters.

ALGO REF NOs: 20

NAME	SYMBOL	UNITS
GAGE-RADAR DIFFERENCE(Normalized)	GRN	unitless

DEF: The normalized difference in accumulation between an hourly gage report and the corresponding radar accumulation, dimensionless.

ALGO REF NOs: 20

NAME	SYMBOL	UNITS
GAGE-RADAR SET	GRS	N/A

DEF: The combination of associated pairs of hourly radar accumulations and hourly gage accumulations.

ALGO REF NOs: 20

NAME SYMBOL UNITS

GAP GAP radians,degrees

DEF: The azimuth width, in radians, separating two VELOCITYs (Range Interval Averaged), between which there is missing or bad data.
-maximum

ALGO REF NOs: 27

GRADIENT G 1/hr

DEF: The gradient of a PATTERN VECTOR (Radial), in 1/hr.
-maximum
-average of the maximum

ALGO REF NOs: 29

HAIL IDENTIFIERS HAP unitless

DEF: Seven weighted predictors used to determine probability of hail production by a STORM.

ALGO REF NOs: 12

HEIGHT H km

DEF: Height of data above ground level, in kilometers.
-difference in height

ALGO REF NOs: 13

HEIGHT(Divergence Feature Center) HDFC km

DEF: The height of the divergence FEATURE center, in kilometers.

ALGO REF NOs: 24

NAME SYMBOL UNITS

HEIGHT(Echo Tops) HTOP km

DEF: Height of non-zero values in CATEGORIES for each SAMPLE VOLUME, in kilometers.

ALGO REF NOs: 13

HEIGHT(Feature Center) HFC km

DEF: The ELEVATION of a FEATURE center, in kilometers.
-lowest
-highest

ALGO REF NOs: 2

HEIGHT(Radar) HR km

DEF: The radar height above sea level, in kilometers.

ALGO REF NOs: 7

HEIGHT(Storm Component-Centroid) HSCC km

DEF: Height of the centroid of a STORM COMPONENT at a particular ELEVATION above the ground, in kilometers.
-difference

ALGO REF NOs: 5,9,12

HEIGHT(Storm Reflectivity) HSZ km

DEF: The height above the ground where reflectivity occurs, in kilometers.
-maximum

ALGO REF NOs: 9

HEIGHT(Storm Spectrum Width) HW km

DEF: The altitude where spectrum width occurs, in kilometers.
-maximum

ALGO REF NOs: 9

HEIGHT(Storm) HSTO km

DEF: The height of a STORM CENTROID (center of mass), in kilometers.

ALGO REF NOs: 5

HEIGHT(TVS Feature) HTVS km

DEF: The height above the ground of a TVS FEATURE, in kilometers.

ALGO REF NOs: 26

HEIGHT(VAD Wind Estimate) HVAD km

DEF: The height above the ground level from which data was collected, in kilometers.

ALGO REF NOs: 7

HYBRID SCAN HS dBZe

DEF: Reflectivity factor data on a 1 degree by 1 km polar grid from 1 to 230 km, in dBZe. These data were composited from four elevation scans by the PRECIPITATION PREPROCESSING algorithm. A precision of at least 1 dBZe and dynamic range of at least 0 to 71 dBZe are required.

ALGO REF NOs: 17,18

NAME SYMBOL UNITS

IDENTIFIER INFORMATION ID hr/min(GMT)

DEF: Consists of annotations such as the radar I.D., product name, time (beginning and ending), date and missing period times. The times must be in hours and minutes GMT (Greenwich Mean Time).

ALGO REF NOs: 21

INDEX INX N/A

DEF: Computed temporary variable ranging from 0 to one less than maximum PROJECTION TIME COUNTER.
-minimum

ALGO REF NOs: 30

INDEX(Azimuth) j N/A

DEF: The index for AZIMUTH.

ALGO REF NOs: 2,7,11,17

INDEX(Elevation) i N/A

DEF: The index for ELEVATION.

ALGO REF NOs: 2,5,7,9,12

INDEX(Slant Range) k N/A

DEF: The index for RANGE(Slant).

ALGO REF NOs: 11,22,23,26

INNOVATIONS INN unitless

DEF: A vector of the differences between the VECTOR(Gage Observation) and the VECTOR(Radar Observation) multiplied by the previous BIAS.
-average

ALGO REF NOs: 20

INNOVATIONS(Decay Parameter) IDP 1/km

DEF: A decay parameter of an isotropic exponential-form covariance function of the difference between the adjusted radar accumulation and the gage accumulation, in 1/km.

ALGO REF NOs: 20

INNOVATIONS(Second Variance Parameter) ISV mm**2

DEF: A second variance parameter which allows for variance at zero distance in addition to the exponential decay portion of an isotropic exponential-form covariance function of the difference between the adjusted radar accumulation and the gage accumulation, in mm**2.

ALGO REF NOs: 20

INNOVATIONS(Variance Parameter) IV mm**2

DEF: A variance parameter of an isotropic exponential-form covariance function of the difference between the adjusted radar accumulation and the gage accumulation, in mm**2.

ALGO REF NOs: 20

INTEGER(Fixed) FIX N/A

DEF: A function that converts the real argument to an integer number by truncation.

ALGO REF NOs: 30

INTERPOLATED VELOCITY(Column) IVEC km/hr

DEF: The interpolated, column-dimension, velocity of a correlation box, computed in the absence of a correlation-based velocity, units of km/hr.

ALGO REF NOs: 34

NAME	SYMBOL	UNITS
INTERPOLATED VELOCITY(Row)	IVER	km/hr

DEF: The interpolated, row-dimension, velocity of a correlation box, computed in the absence of a correlation-based velocity, units of km/hr.

ALGO REF NOs: 34

NAME	SYMBOL	UNITS
INTERVAL(Average)	INA	km

DEF: An interval, in kilometers, over which velocity data are to be averaged over a radial, i.e., the length of a RANGE INTERVAL (6.75 is currently used in NSSL implementation).

ALGO REF NOs: 27

NAME	SYMBOL	UNITS
INTERVAL(Class)	INC	m/s

DEF: One of a set of intervals into which VELOCITYs (Doppler) are divided in order to determine first, the modal (or most frequent value), and then the average value of the VELOCITY(Doppler)over a RANGE INTERVAL. Each INTERVAL(Class) has a width of INTERVAL(Width).

ALGO REF NOs: 27

NAME	SYMBOL	UNITS
INTERVAL(Mode)	INTM	unitless

DEF: The INTERVAL (Class) which contains the most frequently occurring velocity values over a RANGE INTERVAL.

ALGO REF NOs: 27

NAME	SYMBOL	UNITS
INTERVAL(Width)	INW	km/hr

DEF: The width of a class interval for determining an average velocity in a RAGNE INTERVAL (7.2 km/hr is currently used in NSSL implementation).

ALGO REF NOs: 27

NAME SYMBOL UNITS

JINDEX JIN unitless

DEF: Index values that range from 1 to the maximum number of projection time steps in a PROJECTION INTERVAL.

ALGO REF NOs: 30

KINDEX KIN unitless

DEF: Index values that range from JINDEX to the maximum number of projection time steps in a PROJECTION INTERVAL.

ALGO REF NOs: 30

KINEMATIC PARAMETERS KP N/A

DEF: Parameters that are used to estimate atmospheric motions.

ALGO REF NOs: 16

KOLMOGOROV CONSTANT KOL unitless

DEF: A dimensionless constant used to determine turbulence under local isotropic conditions (1.35).

ALGO REF NOs: 23

LABEL LAB N/A

DEF: A descriptive identifier written for each storm, which identifies the probability of hail production as being positive, potential, probable, a non-hail producer, or that there is insufficient data to analyze the storm.

ALGO REF NOs: 12

NAME SYMBOL UNITS

LAGONE AUTOCORRELATION L1A unitless

DEF: LAGONE AUTOCORRELATION of the normalized RESIDUALS.

ALGO REF NOs: 30

LAGZERO AUTOCORRELATION L0A unitless

DEF: LAGZERO AUTOCORRELATION of the normalized RESIDUALS.

ALGO REF NOs: 30

LAYER(Current) LAYC N/A

DEF: Layered reflectivity product generated from the volume scan immediately prior to the time that the algorithm is invoked - a uniform, horizontal cartesian grid of reflectivity pixels for any of the altitude extents available for the LAYER COMPOSITE REFLECTIVITY product, as specified by TYPE (Layer).

ALGO REF NOs: 34

LAYER(Previous) LAYP N/A

DEF: Layered reflectivity product of the same TYPE (Layer) and format as LAYER (Current), but generated from the volume scan preceding that of LAYER (Current).

ALGO REF NOs: 34

LENGTH(Azimuthal) LAZ km

DEF: The length along an azimuth of a FEATURE, in km.

ALGO REF NOs: 29

NAME	SYMBOL	UNITS
LENGTH(Correlation Box)	LEC	km

DEF: The desired length of a side of a correlation box, units of kilometers (28.0).

ALGO REF NOs: 34

NAME	SYMBOL	UNITS
LINDEX	LIN	unitless

DEF: Index values that range from 0 to minimum INDEX.

ALGO REF NOs: 30

NAME	SYMBOL	UNITS
LIQUID WATER	LW	kg/km**3

DEF: The liquid water content for a particular value of reflectivity, in kg/km**3.
-maximum

ALGO REF NOs: 6

NAME	SYMBOL	UNITS
LIQUID WATER(Integrated)	VIL	kg/km**2

DEF: The integrated liquid water values (per grid box), for a column within a STORM, in kg/km**2.
-partial VIL
-maximum

ALGO REF NOs: 6,15

NAME	SYMBOL	UNITS
LIQUID WATER(Integrated-SWP)	VILS	kg/km**2

DEF: The integrated liquid water values in a BOX(SWP) in kg/km**2.
-maximum

ALGO REF NOs: 15

NAME SYMBOL UNITS

LOCATION LOC

DEF: Refers to the BOX location within this grid.
-partial
-box

ALGO REF NOs: 30

MASS MULTIPLICATIVE FACTOR MMF N/A

DEF: A multiplicative factor used in computing the PRECIPITATION INTENSITY (486) (mm**6/m**3)[(hr/mm)]**PIE.

ALGO REF NOs: 22

MASS WEIGHTED FACTOR MWF hr(kg)/km**4

DEF: A factor used in computing the MASS of a (Sample Volume) (53 x 10**9), in hr(kg)/km**4.

ALGO REF NOs: 22

MASS WEIGHTED LENGTH MWL kg/km**2

DEF: Mass density weighted length of a STORM SEGMENT, in kg/km**2.

ALGO REF NOs: 5,22

MASS WEIGHTED LENGTH SQUARED MWS kg/km

DEF: Mass density weighted length squared of a STORM SEGMENT, in kg/km.

ALGO REF NOs: 5,22

NAME	SYMBOL	UNITS
MASS(Sample Volume)	MSV	kg/km**3

DEF: The mass of liquid water content in a SAMPLE VOLUME, in kg/km**3.

ALGO REF NOs: 22

MASS(Storm Component)	MSC	kg/km

DEF: The mass weighted area of a STORM COMPONENT, in (kg/km).

ALGO REF NOs: 5

MASS(Storm)	MST	kg

DEF: The mass weighted volume of a STORM, in kilograms.
-current
-previous

ALGO REF NOs: 4,5,9

MASS-VOLUME RATIO	MVR	unitless

DEF: The ratio of the STORM's mass volume at the current time, to the STORM's mass volume at the previous time. The value is always 1 or greater.

ALGO REF NOs: 4

MATRIX(Covariance Measurement)	MXC	N/A

DEF: A symmetric measurement error covariance matrix.

ALGO REF NOs: 20

NAME SYMBOL UNITS

MATRIX(Gain) MXG N/A

DEF: A vector (1 x N matrix) giving the gain values - the multiplicative factors giving the influence of each innovation on the updated bias.

ALGO REF NOs: 20

MATRIX(Predictor) MXP N/A

DEF: An m by n matrix of predictor variables where m is the dimension for KINEMATIC PARAMETERs and n is the dimension for the Doppler velocities in a SECTOR.

ALGO REF NOs: 16

MAXIMIN MAXIMIN unitless

DEF: The highest of seven adjacent Doppler velocities, which is less than or equal to the current velocity.

ALGO REF NOs: 29

MAXIMUM CENTROID DISTANCE MCD km

DEF: The maximum centroid distance for the STORM COMPONENT at the previous or next previous elevation, in kilometers.

ALGO REF NOs: 5

MAXIMUM DISTANCE FEATURE(Convergence) MFDI km

DEF: A value that represents the maximum horizontal distance that a FEATURE(Convergence) center can travel between two volume scans (5.0), in kilometers.

ALGO REF NOs: 29

NAME SYMBOL UNITS

MAXIMUM FEATURE DISTANCE MFD km

DEF: A value representing the horizontal distance (formed by projecting one FEATURE diameter into the other s plane) limiting vertical correlation of two FEATUREs at consecutive elevation angles, in kilometers. Precise to 1/10**4 km.

ALGO REF NOs: 2

MAXIMUM SAMPLES(Radial) MSR unitless

DEF: The maximum number of SAMPLE VOLUMEs in one radial.

ALGO REF NOs: 33

MEAN GAGE RADAR DIFFERENCE MGR mm

DEF: The mean of the gage-radar differences in precipitation accumulation, in millimeters.

ALGO REF NOs: 20

MEAN SQUARE ERROR MSE unitless

DEF: The reset (long term mean) Mean Square Error (M.S.E.) value used when the M.S.E. has been propagated for an extended time.
-maximum allowed
-previous, current, forecasted, propagated forecast
-reset

ALGO REF NOs: 20

MESOCYCLONE ID MESID N/A

DEF: An ID assigned to a mesocyclone when the MESOCYCLONE Algorithm identifies a mesocyclone.

ALGO REF NOs: 2,26

NAME SYMBOL UNITS

MOMENTUM(Angular) M km**2/hr

DEF: Angular momentum, in km**2/hr.
-average

ALGO REF NOs: 2

MULTIMATRIX MTX N/A

DEF: A modified correlation matrix containing the correlation of errors for each projected RATE with every other projected RATE modified for efficiency of transformation into a covariance matrix and summation of all terms in the covariance matrix.

ALGO REF NOs: 30

NO. OF GRID BOXES WITH VIL > 15 FTN unitless

DEF: Number of grid boxes with VIL greater than 15.

ALGO REF NOs: 15

NO. OF GRID BOXES WITH VIL > 20 TWY unitless

DEF: Number of grid boxes with VIL greater than 20.

ALGO REF NOs: 15

NO. OF GRID BOXES WITH VIL > 25 TWF unitless

DEF: Number of grid boxes with VIL greater than 25.

ALGO REF NOs: 15

NUMBER N unitless

DEF: The number of unique Lanczos Filter Weights to use in actual computation.

ALGO REF NOs: 27

NAME	SYMBOL	UNITS
NUMBER OF POINTS(Box)	NOP	unitless

DEF: The number of reflectivity points in a BOX.

ALGO REF NOs: 11

NUMBER of PATTERN VECTORs (Radial)	NVV	unitless

DEF: The number of PATTERN VECTORs (Radial) comprising a possible FEATURE.

ALGO REF NOs: 29

NUMBER of SAMPLES	NS	unitless

DEF: Number of samples for COUNTER(Storm) NI.
-temporary

ALGO REF NOs: 30

NUMBER(Azimuthal Difference)	NAD	N/A

DEF: Number of azimuthal shear values accumulated at each grid point.

ALGO REF NOs: 33

NUMBER(Data Points)	ND	unitless

DEF: The number of non-missing data points between THRESHOLD (Begin Azimuth) and THRESHOLD (End Azimuth) that went into the Fourier least squares fitting.

ALGO REF NOs: 7

NUMBER(Filter)	NFL	N/A

DEF: Number of data points used in the uniform filter applied to the mean SHEAR(Azimuthal) and mean SHEAR (Radial) fields (9).

ALGO REF NOs: 33

NAME	SYMBOL	UNITS
NUMBER(Good Radial Velocities)	NGR	N/A

DEF: Number of good radial velocity values which have gone into the corresponding average VELOCITY(Doppler) computation.

ALGO REF NOs: 33

NAME	SYMBOL	UNITS
NUMBER(Interpolated Accumulation Outliers)	NAO	N/A

DEF: The number of hourly accumulation sample volumes that contained hourly outliers which could be removed by interpolation.

ALGO REF NOs: 19

NAME	SYMBOL	UNITS
NUMBER(Interpolated Outliers)	NIO	unitless

DEF: Number of SAMPLE VOLUMEs for which the REFLECTIVITY (Interpolated) was computed.

ALGO REF NOs: 17

NAME	SYMBOL	UNITS
NUMBER(Isolated SAMPLE VOLUMES)	NIS	unitless

DEF: Number of SAMPLE VOLUMEs whose REFLECTIVITY FACTOR (DBZE) is greater than the minimum THRESHOLD(Reflectivity) but are surrounded by less than two SAMPLE VOLUMEs whose REFLECTIVITY FACTOR(DBZE) is greater than the minimum THRESHOLD(Reflectivity).

ALGO REF NOs: 17

NAME	SYMBOL	UNITS
NUMBER(Missing Velocity)	NMV	unitless

DEF: Number of the missing velocity in the gap for which an interpolated value is desired.

ALGO REF NOs: 27

NUMBER(Potential Difference Azimuthal) NPDA N/A

DEF: Total number of DIFFERENCE(Azimuthal) values that could potentially contribute to the COMBINED SHEAR, at each grid point if all acceptance criteria are met.

ALGO REF NOs: 33

NUMBER(Potential Difference Radial) NPDR N/A

DEF: Total number of DIFFERENCE(Radial) values that could potentially contribute to the COMBINED SHEAR at each grid point if all acceptance criteria are met.

ALGO REF NOs: 33

NUMBER(Radial Difference) NRD N/A

DEF: Number of radial shear values accumulated at each grid point.

ALGO REF NOs: 33

NUMBER(Replaced Outliers) NRO unitless

DEF: Number of outliers which have at least one neighbor which is also an outlier and whose REFLECTIVITY FACTOR (DBZE) is replaced with the REFLECTIVITY(Tilt Test).

ALGO REF NOs: 17

NUMBER(Sample Volumes) NSV N/A

DEF: Number of contiguous SAMPLE VOLUMEs to be averaged to produce each estimate of average VELOCITY(Doppler) (3). Also used in determining the difference distance for the radial shear computations.

ALGO REF NOs: 33

NAME SYMBOL UNITS

NUMBER(Weights) NWT unitless

DEF: The number of unique Lanczos Filter weights used to obtain the desired filtering characteristics. It must be an odd number with 51 currently being used in the NSSL implementation.

ALGO REF NOs: 27

OBSERVATION(Decay Parameter) OD 1/km

DEF: A decay parameter of a function that improves the mathematical properties of a matrix composed of the outer product of the VECTOR(Radar Observation), in 1/km.

ALGO REF NOs: 20

OBSERVATION(Second Variance Parameter) OSV mm**2

DEF: A second variance parameter of the function that improves the mathematical properties of a matrix composed of the outer product of the VECTOR(Radar Observation) in mm**2.

ALGO REF NOs: 20

OBSERVATION(Variance Parameter) OV mm**2

DEF: A variance parameter of the function that improves the mathematical properties of a matrix composed of the outer product of the VECTOR(Radar Observation), in mm**2.

ALGO REF NOs: 20

OBSERVED ERROR VARIANCE OEV mm**2

DEF: The observed error variance for the i-th BOX (1/40th LFM Grid) for guidance value durations of 1,3 and 6 hours, in (mm**2).

ALGO REF NOs: 31

NAME	SYMBOL	UNITS
OCCULTATION CODEs	OC	unitless

DEF: Coded values for each SAMPLE VOLUME which are based on the percentage of the total (two way) beam intensity which is obscured by natural or man-made obstacles under normal propagation conditions.

ALGO REF NOs: 17

NAME	SYMBOL	UNITS
OCCULTATION(Partial Adjustment)	OCP	dBZe

DEF: An additive adjustment for beam occultation, in dBZe.

ALGO REF NOs: 17

NAME	SYMBOL	UNITS
ORIENTATION	ORI	radians

DEF: The orientation of the maximum and minimum Doppler velocity locations within a FEATURE at the same elevation, in radians.

ALGO REF NOs: 26

NAME	SYMBOL	UNITS
OVERHANG ORIENTATION	OVO	radians

DEF: The overhang between the edge of the STORM COMPONENT at a particular elevation and the centroid of the STORM COMPONENT of the same storm at the lowest elevation, in radians.

ALGO REF NOs: 9

NAME	SYMBOL	UNITS
OVERLAP	OVE	correl. pixels

DEF: The overlap in either dimension of LAYER(Previous), of correlation boxes, units of correlation pixels.

ALGO REF NOs: 34

NAME	SYMBOL	UNITS
PARAMETER(Time Continuity #1)	P1	1/hr

DEF: The allowable rate of change of the ratio of volumetric precipitation rates when the echo area is equal to minimum AREA(Time Continuity), (24.0) in 1/hr. Precise to 0.1 1/hr.

ALGO REF NOs: 18

PARAMETER(Time Continuity #2)	P2	1/hr

DEF: The allowable rate of change of the ratio of volumetric precipitation rates when the echo area is equal to the full radar umbrella out to the 230 km range (13.2), in 1/hr. Precise to 0.1 1/hr.

ALGO REF NOs: 18

PATTERN VECTOR	PVE	N/A

DEF: A vector which is formed when a run of increasing Doppler velocity ends. A PATTERN VECTOR contains seven components: the slant range, the azimuth angles at both ends of the run. the Doppler velocities that correspond to those azimuth angles at the slant range. and the SHEAR(Tangential) and MOMENTUM(Angular). (Angular).

ALGO REF NOs: 2,24

PATTERN VECTOR LIST	PVL	N/A

DEF: The set of all PATTERN VECTORs in a FEATURE.

ALGO REF NOs: 2

PATTERN VECTOR(Radial)	PVER	unitless

DEF: The vector which is formed when a run of decreasing Doppler velocity ends. A velocity vector contains six components: the beginning and ending Doppler velocity. beginning and ending range, azimuth, and maximum gradient.

ALGO REF NOs: 29

NAME SYMBOL UNITS

PERMISSIBLE ERROR PE km

DEF: The maximum error allowed in the forecast of a STORM for each forecast interval, in kilometers.

ALGO REF NOs: 8

PI PI# unitless

DEF: A mathematical constant (3.1416), unitless.

ALGO REF NOs: 2,5,7,9,17,27,29

PIXEL NUMBER PIX unitless

DEF: The number of correlation pixels to a side of a correlation box.

ALGO REF NOs: 34

PIXEL SIZE PS km

DEF: Length of the side of a pixel in the LAYERs, units of kilometers.

ALGO REF NOs: 34

POSITION MAXIMUM SHEAR(Tangential) PMST km,rad,rad

DEF: The RANGE(Slant), beginning pattern vector AZIMUTH and ending pattern vector AZIMUTH where the maximum SHEAR(Tangential) is found in a feature classified as a mesocyclone vortex, in kilometers, radians and radians.

ALGO REF NOs: 2

POSITION(BOX) PB km

DEF: An ordered pair of X and Y coordinates identifying the center of a BOX1, in km.

ALGO REF NOs: 34

POSITION(Mesocyclone) PM km,rad,rad

DEF: The mesocyclone position in range, azimuth and elevation angle, in kilometers, radians and radians.

ALGO REF NOs: 2

POSITION(Optimum Correlation Coefficient) POC km, radians

DEF: An ordered pair of range and azimuth points identifying the position of the optimum correlation coefficient, in kilometers and radians, respectively.

ALGO REF NOs: 11

POSSIBLE COMPONENT PSTC N/A

DEF: A group of SAMPLE VOLUMEs, which are possibly contiguous with respect to range (STORM SEGMENTs) and azimuth, at the same elevation angle. More than one may exist at a given elevation.

ALGO REF NOs: 5

POWER POW dBm

DEF: Received power for each SAMPLE VOLUME, in dBm.

ALGO REF NOs: 33

PRECIPITATION ACCUMULATION PA mm

DEF: The precipitation accumulation in each 1/40th LFM Grid box. The precipitation accumulation refers to the sum of the precipitation accumulation at the current average TIME(Scan) and the projected precipitation.
-total, -zon max tot storm(Guid Dur)
-projected, -total guidance value
-total observed, -maximum total guidance value
-maximum observed,-zonal maximum observed
-total accumulaton

ALGO REF NOs: 30,31

PRECIPITATION FACTOR PF unitless

DEF: A dimensionless factor that accounts for imperfect tracers (large drops), when estimating turbulence.

ALGO REF NOs: 23

PRECIPITATION INTENSITY PIN mm/hr

DEF: Precipitation intensity, in mm/hr (liquid equivalent).

ALGO REF NOs: 22

PRECIPITATION INTENSITY EXPONENT PIE N/A

DEF: The power to which the PRECIPITATION INTENSITY is raised in calculating the effective REFLECTIVITY FACTOR (DBZE)(1.37).

ALGO REF NOs: 22

PRECIPITATION STATUS MESSAGE PSM N/A

DEF: An alphanumeric message which includes the radar ID, TIME(Stamp), current radar status, current operational mode, current scan strategy, TIME(Last Precipitation Detected), CATEGORY(Precipitation), number of gages in data base, and time since last update to the gage data base.

ALGO REF NOs: 17,18,19,20,21

PRECIPITATION TOTAL(Hourly) PTH dBA

DEF: The hourly precipitation total for a particular BOX (2 km x 2 km Grid), in dBA. A precision of at least 0.5 dBA and dynamic range of at least -18 to 32 dBA are required.

ALGO REF NOs: 21

PRECIPITATION TOTAL(Scaled Hourly) PSH unitless

DEF: The scaled hourly precipitation total for a particular BOX(2 km x 2 km Grid). Scale codes from 0 to 15 will be used in assigning colors in the final display.

ALGO REF NOs: 21

PRECIPITATION TOTAL(Scaled Storm) PSS unitless

DEF: The scaled precipitation total for a particular BOX(2 km x 2 km Grid). Scale codes 0 to 15 will be used in assigning colors in the final display.

ALGO REF NOs: 21

PRECIPITATION TOTAL(Scaled Three Hour) PTS unitless

DEF: The scaled three hour precipitation total for a particular BOX(2 km x 2 km Grid). Scale codes from 0 to 15 will be used in assigning colors in the final display.

ALGO REF NOs: 21

PRECIPITATION TOTAL(Storm) PST mm

DEF: The storm precipitation total for a particular BOX(2 km x 2 km Grid), in mm.
-current
-partial
-previous

ALGO REF NOs: 21

NAME	SYMBOL	UNITS
PRECIPITATION TOTAL(Three Hour)	PT3	dBA

DEF: The three hour precipitation total for a particular BOX (2 km x 2 km Grid), in dBA. A precision of at least 0.5 dBA and dynamic range of at least -18 to 32 dBA are required.

ALGO REF NOs: 21

NAME	SYMBOL	UNITS
PROBABILITY(Severe Weather)	PWX	percent

DEF: The probability of severe weather, in percent.

ALGO REF NOs: 15

NAME	SYMBOL	UNITS
PRODUCT(Hourly Precipitation)	PHP	N/A

DEF: The hourly running total or clock hour total on a 2 km x 2 km grid out to 230 kilometers in a 16 level display compatible format, including appropriate supplemental data.

ALGO REF NOs: 21

NAME	SYMBOL	UNITS
PRODUCT(Storm Total Precipitation)	PSP	N/A

DEF: Depicts the total accumulations since the last one hour break in significant precipitation on a 2 km x 2 km grid out to 230 km in a 16 level display-compatible format, including appropriate supplemental data.

ALGO REF NOs: 21

NAME	SYMBOL	UNITS
PRODUCT(Three Hour Precipitation)	P3H	N/A

DEF: The three-hour precipitation accumulation over the past three clock hours on a 2 km x 2 km grid out to 230 km in a 16 level display-compatible format, including appropriate supplemental data.

ALGO REF NOs: 21

NAME SYMBOL UNITS

PROJECTED VARIANCE PV

DEF: Projected variance for the i-th BOX (1/40th LFM Grid).
-total

ALGO REF NOs: 30

PROJECTION INTERVAL LPR hr

DEF: An even multiple of the projection time step for a given projection precipitation (in hours) (0.5-2.0).

ALGO REF NOs: 30

PROJECTION PARAMETER PP unitless

DEF: A single parameter residual decay that allows the residuals to be directly compared from one scan to the next.

ALGO REF NOs: 30

PROJECTION TIME STEP(Hours) Δt hr

DEF: Projection time step(hours) to the nearest 1/1200 hour.

ALGO REF NOs: 30

RADAR OBSERVATION ROB mm

DEF: The radar observation used as part of the gage-radar set by a Kalman filtering procedure. Based on the hourly radar accumulations at the nine sample volumes closest to the gage, in mm.

ALGO REF NOs: 20

NAME SYMBOL UNITS

RADIAL CONVERGENCE RC 1/hr

DEF: The radial convergence in a FEATURE, in 1/hr.
-maximum
-average

ALGO REF NOs: 29

RADIUS CORRECTION(Earth) RCOE unitless

DEF: The factor by which the RADIUS(Earth) is multiplied to account for refraction of the radar beam (1.21).

ALGO REF NOs: 5,9,26

RADIUS(Earth) RE km

DEF: The radius of the Earth (6371), in kilometers.
-effective

ALGO REF NOs: 2,5,6,7,9,13,16,24,26

RADIUS(Inner) RI km/hr

DEF: The inner radius to the nearest 1.0 km, in km/hr.

ALGO REF NOs: 18

RADIUS(Search) RDS km

DEF: The maximum distance the first BOX can search in kilometers.

ALGO REF NOs: 11

RADIUS(Storm Component) RSC km

DEF: The radius of a circle whose area is equivalent to the area of the STORM COMPONENT of a particular STORM at a particular ELEVATION, in kilometers.

ALGO REF NOs: 12

NAME SYMBOL UNITS

RANGE INTERVAL RNT km

DEF: The interval over which to average the velocities over a radial before the wind field is computed in kilometers (6.75 is currently used in NSSL implementation).

ALGO REF NOs: 27

RANGE LIMITS R1-R4 N/A

DEF: Ranges from the radar to the verticies of the Cartesian grid.

ALGO REF NOs: 33

RANGE SAMPLE SPACING RSS km

DEF: The difference in ranges between two adjacent SAMPLE VOLUMEs along a radial, i.e., the length of a SAMPLE VOLUME(1), in kilometers.
-azimuth

ALGO REF NOs: 5,33

RANGE(Bi-Scan) RBS km

DEF: Maximum range at which the bi-scan maximization procedure is applied, in kilometers.

ALGO REF NOs: 17

RANGE(Center Interval) RCI unitless

DEF: The RANGE at the center of a RANGE INTERVAL, i.e., the RANGE(Slant) corresponding to a VELOCITY(Filtered) or a VELOCITY(Range Interval Averaged).

ALGO REF NOs: 27

NAME SYMBOL UNITS

RANGE(Cut-Off) RCO km

DEF: The range beyond which a range effect correction must be applied (150), in kilometers.

ALGO REF NOs: 18

RANGE(Horizontal) RH km

DEF: The horizontal range, in kilometers.

ALGO REF NOs: 6

RANGE(Maximum Velocity) RMV km

DEF: The slant range of maximum VELOCITY(Doppler Range) within a FEATURE, in kilometers.

ALGO REF NOs: 26

RANGE(Maximum) RSM km

DEF: The slant range of maximum VELOCITY(Doppler Range), in kilometers.

ALGO REF NOs: 26

RANGE(Minimum Velocity) RNV km

DEF: The slant range of minimum VELOCITY(Doppler Range) within a FEATURE, in kilometers.

ALGO REF NOs: 26

RANGE(Minimum) RSN km

DEF: The slant range of minimum VELOCITY(Doppler Range), in kilometers.

ALGO REF NOs: 26

NAME	SYMBOL	UNITS
RANGE(Slant Pattern Vector)	RSPV	km

DEF: The RANGE(Slant) of a PATTERN VECTOR, in kilometers.
-beginning
-ending

ALGO REF NOs: 2,24

RANGE(Slant)	RS	km

DEF: The slant range to the center of a SAMPLE VOLUME, in kilometers.
-middle
-average
-maximum, minimum

ALGO REF NOs: 2,6,7,11,13,16-18,22-24,26,27,33

RANGE(Slant-Feature)	RSFE	km

DEF: The slant range of a FEATURE, in kilometers.
-center
-beginning
-ending

ALGO REF NOs: 2,26

RANGE(Slant-Gust Front)	RSVV	km

DEF: The slant ranges of a PATTERN VECTOR (Radial), in kilometers.
-beginning
-ending

ALGO REF NOs: 29

RANGE(Slant-Storm Component)	RSSC	km

DEF: Slant range of a centroid at a particular ELEVATION, in kilometers.

ALGO REF NOs: 12

NAME SYMBOL UNITS

RANGE(Slant-Storm Segment) RSSS km

DEF: The slant range(center of SAMPLE VOLUME) of a STORM SEGMENT, in kilometers.
-beginning
-ending

ALGO REF NOs: 5

RANGE(Tilt Test) RTT km

DEF: The inner and outer range boundaries between which the lowest and second lowest elevation reflectivity data are compared, in kilometers. Will be approximately 40 and 150 km.

ALGO REF NOs: 17

RATE SCAN RSP dBR

DEF: Precipitation rate data on a 1 degree by 2 km polar grid from 1 to 230 km, in dBR. A precision of at least 0.5 dBR and a dynamic range of at least -18 to 32 dBR are required (not generated for times when FLAG(Zero Rate) or when FLAG(Bad) are set).
-current, previous

ALGO REF NOs: 18,19,30

RATE(1/4th LFM Grid Box) RGB N/A

DEF: Area-average rate (8 level coded value) in each 1/4 LFM grid square. A 13 by 13 grid of values for each RATE SCAN used in constructing the hourly accumulations.

ALGO REF NOs: 18,21

RATE(Complete Reference) RCR mm(km**2)/hr

DEF: The RATE(Complete Volumetric Precipitation) for the last good scan, in mm(km**2)/hr.

ALGO REF NOs: 18

NAME	SYMBOL	UNITS
RATE(Complete Volumetric Precipitation)	RVP	mm (km**2)/hr

DEF: The total volumetric precipitation rate over the entire field of view out to 230 km, in mm (km**2)/hr.

ALGO REF NOs: 18

RATE(Echo Area Change)	RAC	km**2/hr

DEF: Rate of change of echo area allowed to pass the time continuity test when the volumetric precipitation rate cannot be tested due to the minimum AREA(Time Continuity), in km**2/hr.
-maximum

ALGO REF NOs: 18

RATE(Inner Reference)	RIR	mm(km**2)/hr

DEF: The RATE(Inner Volumetric Precipitation) for the last good scan, in mm(km**2)/hr.
-maximum

ALGO REF NOs: 18

RATE(Inner Volumetric Precipitation)	RIV	mm km**2/hr

DEF: The total volumetric precipitation rate within the RADIUS(Inner), in mm km**2/hr.
-maximum

ALGO REF NOs: 18

RATE(Mean)	MR	mm/hr

DEF: Mean(RATE) for COUNTER(Storm) NI (in mm/hr).

ALGO REF NOs: 30

RATE(Precipitation) RR mm/hr

DEF: Total RATE of precipitation for COUNTER(Storm) NI (in mm/hr).
- -adjusted
- -temporary; temporary squared
- -squared error variance
- -projected
- -squared (mm/hr)**2
- -total
- -total error variance

ALGO REF NOs: 30

RATE(Range Corrected Precipitation) RRC dBR

DEF: Rate(Range Corrected Precipitation), the RATE(Range Corrected Precipitation), with a precision of at least 0.5 dBR and a dynamic range of -18 to 32 dBR are required, in dBR.

ALGO REF NOs: 18

RATE(Standard Deviation) SD mm/hr

DEF: The standard deviation of the rate for COUNTER(Storm) NI (in mm/hr).

ALGO REF NOs: 30

RATE(Zero Precipitation) RZP dBR

DEF: Precipitation rate assumed to be zero precipitation (-17.5), in dBR.

ALGO REF NOs: 18

RATIO(Bi-Scan) BIR unitless

DEF: The ratio of the number of SAMPLE VOLUMEs used from the second lowest elevation scan to the total number of SAMPLE VOLUMEs used in the Bi-Scan maximization procedure.

ALGO REF NOs: 17

NAME SYMBOL UNITS

RATIO(Diameter) ROD unitless

DEF: The ratio of the azimuthal diameter to the radial diameter of a FEATURE.

ALGO REF NOs: 2

RATIO(Minimum) RATM unitless

DEF: The minimum MASS-VOLUME RATIO needed before the distance correlation will be made. This is a site-adaptable parameter with the current implementation NSSL value being 10.

ALGO REF NOs: 4

RATIO(Momentum Diameter) RMD unitless

DEF: The ratio of the momentum weighted azimuthal diameter to the radial diameter of a FEATURE.

ALGO REF NOs: 2

REFLECTIVITY AVERAGING FACTOR ZU unitless

DEF: The number of SAMPLE VOLUMES used for determining the average REFLECTIVITY FACTOR(DBZE)(3).

ALGO REF NOs: 22

REFLECTIVITY FACTOR(DBZE) DBZE dBZe

DEF: The effective radar reflectivity factor of a SAMPLE VOLUME, in dBZe.
-maximum, average
-first-scan and second-scan

ALGO REF NOs: 5,9,11,17,18,22,23,24,29

NAME SYMBOL UNITS

REFLECTIVITY FACTOR(ZE) ZE mm**6/m**3

DEF: The effective radar reflectivity factor of a SAMPLE VOLUME, in mm**6/m**3.

ALGO REF NOs: 6,7,22

REFLECTIVITY(Area-Averaged) ZAV dBZe

DEF: The area-averaged reflectivity factor for all SAMPLE VOLUMES from the lowest elevation sector between the inner and outer RANGEs(Tilt Test) with reflectivity factor greater than or equal to the REFLECTIVITY (Tilt Test), in dBZe.
-minimum
-lowest

ALGO REF NOs: 17

REFLECTIVITY(Complete Occultation) ZCO dBZe

DEF: The average of the reflectivity factor values at the same range on either side of a completely occulted SAMPLE VOLUME, in dBZe.

ALGO REF NOs: 17

REFLECTIVITY(Interpolated) ZEI dBZe

DEF: The average of all eight neighboring SAMPLE VOLUME reflectivities, in dBZe.

ALGO REF NOs: 17

REFLECTIVITY(Pixel) ZPI dBZe

DEF: REFLECTIVITY value of a pixel in LAYER(Previous) or LAYER(Current), units of dBZe.

ALGO REF NOs: 34

NAME	SYMBOL	UNITS
REFLECTIVITY(Storm Component)	ZSC	dBZe

DEF: Effective reflectivity value detected in an individual STORM COMPONENT, in dBZe.
-maximum

ALGO REF NOs: 5,12

REFLECTIVITY(Storm)	ZS	dBZe

DEF: The effective reflectivity value detected among all STORM COMPONENTs of each STORM, in dBZe.
-maximum

ALGO REF NOs: 9,12

REFLECTIVITY(Tilt Test)	ZTT	dBZe

DEF: Low reflectivity, approximately 0 - 10 dBZe.

ALGO REF NOs: 17

RESIDUAL(Normalized)	NRT	unitless

DEF: Normalized RESIDUAL at the i-th BOX for the current scan.
-previous
-temporary
-current

ALGO REF NOs: 30

ROOT MEAN SQUARE	RMS	km/hr

DEF: The square root of mean squared deviations of Doppler velocities from a Fourier least-squares fit curve, in km/hr.

ALGO REF NOs: 7

NAME	SYMBOL	UNITS
ROTATION	ROT	radians

DEF: The rotation of the velocity field within a FEATURE at the same elevation, in radians.

ALGO REF NOs: 26

NAME	SYMBOL	UNITS
ROW DISPLACEMENT(Correlation Maximum)	DPRM	correl. pixels

DEF: Row displacement of the correlation box in LAYER (Previous) yielding the maximum value of CORRELATION (Box Displacement), units of correlation pixels.

ALGO REF NOs: 34

NAME	SYMBOL	UNITS
ROW DISPLACEMENT(Interpolated)	DPRI	correl. pixels

DEF: Quadratic estimate of peak location in correlation surface sampled in FIELD (correlation) in the row dimension, units of correlation pixels.

ALGO REF NOs: 34

NAME	SYMBOL	UNITS
ROW VELOCITY	VELR	km/hr

DEF: Correlation-based estimate of the velocity of a correlation box in the row dimension of LAYER(Previous), units of km/hr.

ALGO REF NOs: 34

NAME	SYMBOL	UNITS
SAMPLE SIZE(Counter)	SM6	unitless

DEF: Sample size counter for storm INITIATION SUMs.

ALGO REF NOs: 30

NAME	SYMBOL	UNITS
SAMPLE VALUES	SVA	

DEF: Values computed for the determination of the grid box observed error variance.
-Grid Box

ALGO REF NOs: 30

NAME	SYMBOL	UNITS
SAMPLE VOLUME	SV	N/A

DEF: A data sample volume whose dimensions are 1 degree in azimuth, 1 km in range, and 1 degree in depth (perpendicular to the radar beam).
-.25 bin in range for radial velocity and spectrum width measurements

ALGO REF NOs: 2,17,19,22,23,29

NAME	SYMBOL	UNITS
SCORE	SCR	percent

DEF: A ratio of the total weight of the positive HAIL IDENTIFIERS to the total possible weight of all succesful tests, in percent.

ALGO REF NOs: 12

NAME	SYMBOL	UNITS
SEARCH BOUNDARY	SB	km and radians

DEF: The boundary (including SEARCH PERCENTAGE) of the area enclosing a FEATURE, in range and azimuth.

ALGO REF NOs: 26

NAME	SYMBOL	UNITS
SEARCH BOUNDARY (Azimuth)	SBA	radians

DEF: The azimuth of a FEATURE adjusted for the SEARCH PERCENTAGE, in radians.
-beginning, ending

ALGO REF NOs: 26

NAME SYMBOL UNITS

SEARCH BOUNDARY(Slant Range) SBR km

DEF: The slant range of a FEATURE adjusted for the search PERCENTAGE, in kilometers.
-beginning, ending

ALGO REF NOs: 26

SEARCH PERCENTAGE PCT unitless

DEF: The percent areal increase for searching for TVSs (.05), unitless (.05 is equivalent to 5 percent).

ALGO REF NOs: 26

SECOND-ORDER FIT SOF N/A

DEF: Curves fit to range and azimuth data to determine the optimum correlation coefficient location using second-order polynomials.

ALGO REF NOs: 11

SECTOR SEC radians,km

DEF: Reflectivity values from a subset of a radar scan in a Pi/6 radians by 30 kilometer by 2 elevation angle volume, in radians and kilometers.

ALGO REF NOs: 16

SECTOR(Transverse Wind) STW radians

DEF: Reflectivity values from a subset of a radar scan determined by a minimum and maximum range, and minimum and maximum azimuth, in radians.

ALGO REF NOs: 11

NAME SYMBOL UNITS

SEVERE WEATHER COEFFICIENTS SW1...SW6 N/A

DEF: The set of coefficients of a regression equation that determines the severe weather probability. The default values are SW1=6.90, SW2=7.39, SW3=0.22, SW4=3.67, SW5=0.01 and SW6=2.55.

ALGO REF NOs: 15

SHAPE(AXIS2) SAX2 km

DEF: The second axis of an ellipse defined by the SHAPE (Length) calculated from the area of the STORM COMPONENT, in kilometers.

ALGO REF NOs: 5

SHAPE(Ellipticity) SELP N/A

DEF: The ratio of the axis length of the ellipse defined by SHAPE(Length) and SHAPE(AXIS2). A dimensionless quantity ranging between 0 and 1.

ALGO REF NOs: 5

SHAPE(Length) SLEN km

DEF: The distance between the points located by the beginning AZIMUTH RANGE(Slant) and the first azimuth of a STORM COMPONENT, and the ending AZIMUTH RANGE(SLANT) and the last azimuth of a STORM COMPONENT, in kilometers.

ALGO REF NOs: 5

SHAPE(Orientation) SORI radians

DEF: The orientation of the ellipse represented by SHAPE (Length) and SHAPE(AXIS2), in radians.

ALGO REF NOs: 5

NAME SYMBOL UNITS

SHEAR POSITION SHP km/radians

DEF: The position in range and azimuth of the maximum SHEAR (TVS) position.

ALGO REF NOs: 26

SHEAR POSITION(Azimuth) SRA radians

DEF: The azimuth of the SHEAR POSITION, in radians.

ALGO REF NOs: 26

SHEAR POSITION(Range) SRR km

DEF: The slant range of the SHEAR POSITION, in kilometers.

ALGO REF NOs: 26

SHEAR(Azimuthal) SA N/A

DEF: Shear(Azimuthal) values.
-filtered
-mean

ALGO REF NOs: 33

SHEAR(Radial) S 1/hr

DEF: The change in Doppler velocity along a radial, in 1/hr.
-average

ALGO REF NOs: 24

SHEAR(Radial-RSA) SR N/A

DEF: Shear(Radial-RSA) values.
-filter
-mean

ALGO REF NOs: 33

NAME SYMBOL UNITS

SHEAR(TVS) STV 1/hr

DEF: The change between the maximum and minimum Doppler velocities within a FEATURE at the same elevation, in 1/hr.
-maximum

ALGO REF NOs: 26

SHEAR(Tangential) SRT 1/hr

DEF: The change in Doppler velocity for a PATTERN VECTOR divided by its length, in 1/hr.
-maximum, average, maximum average

ALGO REF NOs: 2

SLOPE SLP (km**2/3)/km

DEF: The slope, between ranges 0 and 5 km, of the curve that estimates the SPECTRUM WIDTH(Normalized Variance), in (km**2/3)/km.

ALGO REF NOs: 23

SPACING(Correlation Box) SPC km

DEF: The desired spacing of correlation box centers in the row and column dimensions of LAYER(Previous), units of km(28.0).

ALGO REF NOs: 34

SPECTRUM WIDTH W km/hr

DEF: Spectrum width value, in km/hr.
km/hr.
-maximum

ALGO REF NOs: 5,9,22

NAME	SYMBOL	UNITS
SPECTRUM WIDTH(Normalized Variance)	WNV	km**2/3

DEF: The normalized SPECTRUM WIDTH(Variance), in km**2/3.

ALGO REF NOs: 23

SPECTRUM WIDTH(Variance)	WV	km**2/hr**2

DEF: The variance of Doppler spectrum for a data SAMPLE VOLUME, in km**2/hr**2.

ALGO REF NOs: 23

SPEED(Horizontal Wind)	SHW	km/hr

DEF: Horizontal wind speed, in km/hr.
-average

ALGO REF NOs: 7,11

SPEED(Mean)	SPM	km/hr

DEF: The SPEED(Storm) either obtained from the average of SPEED(Storm) or operator input, in km/hr. If neither is available, a default value of 0 will be used.

ALGO REF NOs: 4

SPEED(Minimum)	SPDM	km/hr

DEF: The minimum SPEED a STORM must have in order for a 360 degree search to be conducted to find its next position (for STORMs moving faster than this SPEED, a smaller search window is used) (2), in km/hr.

ALGO REF NOs: 4

NAME SYMBOL UNITS

SPEED(Rotational) SPR km/hr

DEF: Half the momentum weighted diameter of a feature times the average SHEAR(Tangential), in km/hr. Precise to .36 km/hr.
-average

ALGO REF NOs: 2

SPEED(Storm Limit) SPL km/hr

DEF: Maximum possible speed for reflectivity features in LAYER(Previous), units of km/hr(120).

ALGO REF NOs: 34

SPEED(Storm) SS km/hr

DEF: Speed of a STORM, in km/hr.
-average and climatologically derived maximum
-direction of a STORM
-If the speed is not determined by the STORM POSITION FORECAST[008] algorithm, then its value is set as unknown.
-maximum, to the nearest 1.0 km/hr.

ALGO REF NOs: 8,9,11,12,18

SPEED(Vertical Wind Change) SVC 1/hr

DEF: The rate of change of the vertical wind speed at a specific altitude, in (km/hr)/km or 1/hr.

ALGO REF NOs: 7

SPEED(Vertical Wind) SVW km/hr

DEF: The vertical wind speed (positive upward), in km/hr.

ALGO REF NOs: 7

NAME	SYMBOL	UNITS
SPEED(Wind)	SPW	km/hr

DEF: The horizontal wind speed not corrected for the elevation angle of measurement, in km/hr.

ALGO REF NOs: 7

NAME	SYMBOL	UNITS
STANDARD DEVIATION GAGE-RADAR DIFFERENCE	SGR	mm

DEF: The standard deviation of the gage-radar difference in precipitation accumulation, in millimeters.

ALGO REF NOs: 20

NAME	SYMBOL	UNITS
STORM	ST	N/A

DEF: A three-dimensional region composed of STORM COMPONENTs characterized by reflectivity values above a given threshold, ordered by mass weighted volume.
-unordered storm

ALGO REF NOs: 4,5,8,9,12

NAME	SYMBOL	UNITS
STORM BASE	STB	km

DEF: The altitude of the base of the storm (lowest STORM COMPONENT), in kilometers.

ALGO REF NOs: 9

NAME	SYMBOL	UNITS
STORM COMPONENT	STC	N/A

DEF: A group of SAMPLE VOLUMEs, contiguous with respect to range (STORM SEGMENTs) and azimuth, at the same elevation angle. More than one may exist at a given elevation.

ALGO REF NOs: 5,12

NAME SYMBOL UNITS

STORM DYNAMICS(Multi COUNTER(Storm) Method) SDM N/A

DEF: A computation that determines the mean precipitation and standard deviation of a COUNTER(Storm), that does not meet the initial THRESHOLD(Minimum NUMBER of SAMPLES) criteria by adding samples from adjacent COUNTERs (Storm) until the THRESHOLD(Minimum NUMBER of SAMPLES) is met.

ALGO REF NOs: 30

STORM DYNAMICS(Projected) STP N/A

DEF: States that the mean and standard deviation for all COUNTER(Storm) beyond the maximum available COUNTER (Storm) are presumed equal to the maximum available COUNTER(Storm) (simple persistence).

ALGO REF NOs: 30

STORM DYNAMICS(Single COUNTER(STORM) Method) SDS N/A

DEF: A computation that determines the mean precipitation of a COUNTER(Storm) and its standard deviation, if the THRESHOLD(Minimum NUMBER of SAMPLES) is met.

ALGO REF NOs: 30

STORM INITIATION DECAY SID unitless

DEF: A decay parameter which determines the weight to be placed on previous storm motion information (0.8-1.0).

ALGO REF NOs: 30

STORM INITIATION OFFSET OF unitless

DEF: Storm Initiation Offset.
-maximum, negative Y-direction
-maximum, positive Y-direction
-Y-direction
-X-direction

ALGO REF NOs: 30

NAME	SYMBOL	UNITS
STORM INITIATION OFFSET LIMITS	DYP	unitless

DEF: Storm Initiation Offset Limits in the Y-direction.

ALGO REF NOs: 30

STORM INITIATION OFFSET TIME	TOF	unitless

DEF: Values of the Storm Initation Offset time are integers ranging from zero to the number of time steps for which the storm projection is made. They are uniformly distributed (approximately) so that the number of entries in the Storm Initiation Offset table with any particular value of the Storm Initiation Offset time will approximately be the number of Storm Initiation Offsets divided by the quantity (number of time steps of projection plus one).

ALGO REF NOs: 30

STORM INITIATION PARAMETERs	IP1,IP2	unitless

DEF: Storm INITIATION PARAMETERs (IP1 and IP2).

ALGO REF NOs: 30

STORM INITIATION SUM	SM1-5,7,8	unitless

DEF: Storm INITIATION SUMs (SM1-SM5,SM7,SM8).

ALGO REF NOs: 30

STORM INITIATION WIDTH	D	N/A

DEF: This is the width of the rectangular region (searched "upwind") for storm initiation (1-2), in km.

ALGO REF NOs: 30

NAME	SYMBOL	UNITS
STORM OVERHANG	OVH	km

DEF: The distance between the edge of the STORM COMPONENT at a particular ELEVATION and the centroid of another STORM COMPONENT of the same storm at the lowest ELEVATION, in kilometers.

ALGO REF NOs: 9,12

NAME	SYMBOL	UNITS
STORM SEGMENT	SMT	N/A

DEF: A set of numbered, contiguous SAMPLE VOLUMEs along a radial identified by reflectivity factor values above a specifed threshold. A STORM SEGMENT includes: beginning RANGE(Slant), ending RANGE(Slant), maximum REFLECTIVITY FACTOR(DBZE), most minimum and most maximum VELOCITY(Doppler), maximum SPECTRUM WIDTH, AZIMUTH and ELEVATION angle.

ALGO REF NOs: 5,22

NAME	SYMBOL	UNITS
STORM SPECTRUM WIDTH	SSW	km/hr

DEF: The width of a STORM, in km/hr.
-maximum

ALGO REF NOs: 9

NAME	SYMBOL	UNITS
STORM TILT	STI	radians

DEF: The angle (with respect to the Z-axis) between the centroid position of the STORM COMPONENT at the lowest elevation and another STORM COMPONENT within the same storm, in radians.

ALGO REF NOs: 9

NAME	SYMBOL	UNITS
STORM TOP	STT	km

DEF: The height above the ground of the centroid of the highest STORM COMPONENT, in kilometers.

ALGO REF NOs: 9,12

NAME	SYMBOL	UNITS
STORM VELOCITY(Lowest Elevation)	STE	km/hr

DEF: The storm velocity at the lowest ELEVATION, in km/hr.
-maximum

ALGO REF NOs: 9

STORM(X-tilt)	STX	radians

DEF: The storm tilt along the X-axis between the centers of mass of STORM COMPONENTs at different ELEVATIONs, in radians.

ALGO REF NOs: 9

STORM(Y-tilt)	STY	radians

DEF: The storm tilt along the Y-axis between the centers of mass at STORM COMPONENTs at different ELEVATIONs, in radians.

ALGO REF NOs: 9

SUM(Azimuthal Difference)	SAD	N/A

DEF: Sum of the azimuthal differences at each Cartesian grid point.

ALGO REF NOs: 33

SUM(Radial Difference)	SRD	N/A

DEF: Sum of the radial differences at each Cartesian grid point.

ALGO REF NOs: 33

NAME	SYMBOL	UNITS
SUM1	SUM1	N/A

DEF: A computed temporary variable used to compute the terms in MULTIMATRIX.

ALGO REF NOs: 30

SUPPLEMENTAL DATA	SUP	N/A

DEF: A set of data which will be included as annotations to the four precipitation products.

ALGO REF NOs: 21

SWP BOX SIZE	SBS	km

DEF: The size of the SWP analysis area, in odd numbered multiples of 4 x 4 kilometer boxes (e.g. 28 x 28, 36 x 36, 44 x 44...etc.). The default size 44 x 44 kilometers.

ALGO REF NOs: 15

SYMMETRY	SYMM	N/A

DEF: A flag value that is positive if the absolute value of COEFFICIENT(Fourier, #1) is less than THRESHOLD (Symmetry) and the absolute value of COEFFICIENT (Fourier, #1) minus SPEED(Wind) is less than or equal to zero.

ALGO REF NOs: 7

SYSTEM NOISE	SYS	N/A

DEF: The estimated mean square error of the drift in the radar BIAS from one hour to the next (0.05).

ALGO REF NOs: 20

NAME SYMBOL UNITS

TARGET BOX TBX N/A

DEF: These are the boxes searched for "upwind" of the grid box with a COUNTER(Storm) of zero. These boxes are searched for "upwind" until precipitation is detected at the TARGET BOX. The OFx, OFy and TOF from this TARGET BOX to the grid box with a COUNTER(Storm) of zero is obtained from the Storm Initiation Offset Table.

ALGO REF NOs: 30

TEMPORARY SUM TS1-TS5 unitless

DEF: TEMPORARY SUMs (TS1 - TS5) used in Storm initiation computation.

ALGO REF NOs: 30

TENDENCY TCY unitless

DEF: The trend in Doppler velocities (increasing (+), decreasing (-)) in the azimuthal direction.

ALGO REF NOs: 2

THRESHOLD(Azimuth) TAZ radians

DEF: The maximum azimuthal separation between PATTERN VECTORs (0.035), in radians.

ALGO REF NOs: 24

THRESHOLD(Begin Azimuth) TBZ radians

DEF: Starting azimuth for VAD analysis, in radians.

ALGO REF NOs: 7

NAME	SYMBOL	UNITS
THRESHOLD(Combined Shear)	THCS	1/hr

DEF: The minimum combined shear value allowed for acceptance in the final shear field (8-16), in 1/hr.

ALGO REF NOs: 33

NAME	SYMBOL	UNITS
THRESHOLD(Convergence Azimuth)	TCA	degrees

DEF: A value that represents the maximum azimuthal separation between PATTERN VECTORs (Radial) (4), in degrees.

ALGO REF NOs: 29

NAME	SYMBOL	UNITS
THRESHOLD(Convergence Range)	TCR	km

DEF: A value that represents the maximum range separation between (PATTERN VECTORs (Radial))(4.0), in kilometers.

ALGO REF NOs: 29

NAME	SYMBOL	UNITS
THRESHOLD(Correlation)	THCO	N/A

DEF: Minimum value of a correlation coefficient to be accepted for displacement calculations.

ALGO REF NOs: 34

NAME	SYMBOL	UNITS
THRESHOLD(Data Points)	TDP	unitless

DEF: The minimum number of data points allowed for the Fourier least squares fitting (25), unitless.

ALGO REF NOs: 7

NAME	SYMBOL	UNITS
THRESHOLD(Direction Angle)	TDA	N/A

DEF: The maximum acceptable deviation of a STORM direction compared to the average direction of all STORMs (1.57), in radians.

ALGO REF NOs: 12

NAME SYMBOL UNITS

THRESHOLD(Divergence Range) TDI km

DEF: A value that represents the maximum range separation between PATTERN VECTOR centers (3.5), in kilometers.

ALGO REF NOs: 24

THRESHOLD(Divergence-High Shear) TDHS 1/hr

DEF: A value which represents the minimum magnitude of shear expected in divergence in the presence of minimal air mass flux(7.2), in 1/hr.

ALGO REF NOs: 24

THRESHOLD(Divergence-Low Shear) TDLS 1/hr

DEF: A value which represents the minimum magnitude of shear expected in divergence(3.6), in 1/hr.

ALGO REF NOs: 24

THRESHOLD(Dropout Number) TDN N/A

DEF: The maximum number of SAMPLE VOLUMEs below THRESHOLD (Reflectivity) and above THRESHOLD(Dropout Reflectivity) that may be included in a STORM SEGMENT (2).

ALGO REF NOs: 22

THRESHOLD(Dropout Reflectivity) TDR dBZe

DEF: The minimum effective reflectivity of SAMPLE VOLUMEs that are below THRESHOLD(Reflectivity) that may still be included in a STORM SEGMENT (25), in dBZe.

ALGO REF NOs: 22

NAME SYMBOL UNITS

THRESHOLD(End Azimuth) TEZ radians

DEF: Ending azimuth for VAD analysis, in radians.

ALGO REF NOs: 7

THRESHOLD(Far Maximum Ratio) TFMX unitless

DEF: A maximum value which represents the upper bound of a range of values related to the ratio of radial and azimuthal diameters of a FEATURE at ranges further than THRESHOLD(Range) (4.0).

ALGO REF NOs: 2

THRESHOLD(Far Minimum Ratio) TFMN unitless

DEF: A minimum value which represents the lower bound of a range of values related to the ratio of radial and azimuthal diameters of a FEATURE at ranges further than THRESHOLD(Range) (1.6).

ALGO REF NOs: 2

THRESHOLD(Feature Height) TFH km

DEF: A value that represents the maximum height of possible mesocyclone FEATUREs (8 km), in kilometers.

ALGO REF NOs: 2

THRESHOLD(Gage Discard) TGD unitless

DEF: Threshold value of the normalized gage-radar difference to discard the gage data value. A dimensionless number.

ALGO REF NOs: 20

THRESHOLD(Good Pixels) TGP correl. pixels

DEF: THRESHOLD(Pixel Fraction) normalized by the number of pixels in a correlation box, units of correlation pixels.

ALGO REF NOs: 34

THRESHOLD(Hail #1) TH1 km

DEF: The minimum STORM TOP height to identify HAIL IDENTIFIER #1 (8), in kilometers.

ALGO REF NOs: 12

THRESHOLD(Hail #2) TH2 dBZe

DEF: The minimum maximum REFLECTIVITY(Storm) to identify HAIL IDENTIFIER #2 (55), in dBZe.

ALGO REF NOs: 12

THRESHOLD(Hail #4) TH4 radians

DEF: The angle between the overhang and the direction to identify HAIL IDENTIFIER #4 (.785 through 3.14), in radians.

ALGO REF NOs: 12

THRESHOLD(Hail #5) TH5 dBZe

DEF: The minimum REFLECTIVITY(Storm Component) used to identify HAIL IDENTIFIER #5 (50), in dBZe.

ALGO REF NOs: 12

THRESHOLD(Hail #6) TH6 km

DEF: The minimum STORM OVERHANG used to identify HAIL IDENTIFIER #6 (4), in kilometers.

ALGO REF NOs: 12

THRESHOLD(Hail Height) THA km

DEF: The height of a mid-level STORM COMPONENT, used to identify HAIL IDENTIFIERS #3, #4, #5 and #6 (5-12), in kilometers.

ALGO REF NOs: 12

THRESHOLD(Hail High Low) THL km

DEF: The maximum height of the centroid of the STORM COMPONENT, used to identify HAIL IDENTIFIERs #2, #3 and #4 (5), in kilometers.

ALGO REF NOs: 12

THRESHOLD(Hail Low) THW km

DEF: The maximum height of the lowest elevation STORM COMPONENT, used to identify HAIL IDENTIFIER #3, #4 and #6 (5), in kilometers.

ALGO REF NOs: 12

THRESHOLD(Height) THH km

DEF: Only pattern vectors above this height threshold will be checked for divergence (8), in kilometers.

ALGO REF NOs: 24

THRESHOLD(High Confidence) THC N/A

DEF: The minimum value to label a STORM as a hail producer (50).

ALGO REF NOs: 12

THRESHOLD(High Convergence Flux) THCF km**2/hr

DEF: A value that represents the minimum magnitude of flux expected in convergence in the presence of minimal shear (361), in km**2/hr.

ALGO REF NOs: 29

THRESHOLD(High Flux) THF 1/hr

DEF: A value which represents the minimum magnitude of air mass flux expected in divergence in the presence of minimal shear (108), in 1/hr.

ALGO REF NOs: 24

THRESHOLD(High Gradient) THG (km/hr)/km

DEF: A value that represents the minimum magnitude of Doppler velocity gradient in the presence of minimal convergence flux (2.34), in (km/hr)/km.

ALGO REF NOs: 29

THRESHOLD(High Momentum) THM km**2/hr

DEF: A value which represents the minimum magnitude of angular momentum expected in a mesocyclone in the presence of low shear, in 540.0 km**2/hr.

ALGO REF NOs: 2

NAME SYMBOL UNITS

THRESHOLD(High Reflectivity) TR dBZe

DEF: The maximum REFLECTIVITY FACTOR(DBZE) above which the STORM is labelled to be a probable hail producer (70), in dBZe.

ALGO REF NOs: 12

THRESHOLD(High Score) THI unitless

DEF: The minimum score to label a hail producer (60).

ALGO REF NOs: 12

THRESHOLD(Hourly Outlier) THO dBA

DEF: The maximum hourly rainfall amount in an hourly accumulation scan sample volume (26.0), in dBA.

ALGO REF NOs: 19

THRESHOLD(Low Confidence) TLC N/A

DEF: The minimum CONFIDENCE FACTOR to compute a SCORE (25).

ALGO REF NOs: 12

THRESHOLD(Low Convergence Flux) TLCF km**2/hr

DEF: A value that represents the minimum magnitude of flux expected in convergence (108), in km**2/hr.

ALGO REF NOs: 29

THRESHOLD(Low Flux) TLF 1/hr

DEF: A value which represents the minimum magnitude of air mass flux expected in divergence (36), in 1/hr.

ALGO REF NOs: 24

NAME SYMBOL UNITS

THRESHOLD(Low Gradient) TLG (km/hr)/km

DEF: A value that represents the minimum magnitude of Doppler velocity gradient (1.8), in (km/hr)/km.

ALGO REF NOs: 29

THRESHOLD(Low Momentum) TLM km**2/hr

DEF: A value which represents the minimum magnitude of angular momentum in a mesocyclone, in 180.0 km**2/hr.

ALGO REF NOs: 2

THRESHOLD(Max Time Difference) TMT hr

DEF: Maximum time between scans (approximately 0.25 hours) allowed by the time continuity test.

ALGO REF NOs: 18

THRESHOLD(Maximum Ratio) TMR unitless

DEF: A maximum value which represents the upper bound of a range of values related to the ratio of radial and azimuthal diameters of a FEATURE at ranges closer than THRESHOLD(Range) (2.0).

ALGO REF NOs: 2

THRESHOLD(Mesocyclone Azimuth) TMA radians

DEF: A value that represents the maximum tangential separation of PATTERN VECTORs to be considered part of the same FEATURE (0.034), in radians.

ALGO REF NOs: 2

NAME SYMBOL UNITS

THRESHOLD(Mesocyclone-High Shear) TMHS 1/hr

DEF: A value which represents the minimum magnitude of shear expected in a mesocyclone in the presence of low angular momentum, in 14.4 1/hr.
-maximum

ALGO REF NOs: 2

THRESHOLD(Mesocyclone-Low Shear) TMLS 1/hr

DEF: A value which represents the minimum magnitude of shear expected in a mesocyclone, in 7.2 1/hour.

ALGO REF NOs: 2

THRESHOLD(Minimum NUMBER of SAMPLES) TMN N/A

DEF: Minimum NUMBER of SAMPLES needed for a valid statistical analysis.

ALGO REF NOs: 30

THRESHOLD(Minimum Ratio) TRM unitless

DEF: A minimum value which represents the lower bound of a range of values related to the ratio of radial and azimuthal diameters of a FEATURE at ranges closer than THRESHOLD(Range) (0.5).

ALGO REF NOs: 2

THRESHOLD(Minimum Reflectivity-2) THR2 dBZe

DEF: The minimum effective reflectivity in a SAMPLE VOLUME to be included in a STORM SEGMENT (30), in dBZe.

ALGO REF NOs: 22

NAME	SYMBOL	UNITS
THRESHOLD(Number of Sets)	TNS	unitless

DEF: The minimum number of GAGE-RADAR SETs for which covariance estimation is allowed (2-10).

ALGO REF NOs: 20

NAME	SYMBOL	UNITS
THRESHOLD(Number)	NTH	unitless

DEF: The minimum fraction of NUMBER(Radial Difference) to NUMBER(Potential Difference Radial) and of NUMBER (Azimuthal Difference) to NUMBER (Potential Difference Azimuthal) for the calculations of the respective shears (.75).

ALGO REF NOs: 33

NAME	SYMBOL	UNITS
THRESHOLD(Overlap)	TOV	unitless

DEF: Minimum number of SAMPLE VOLUMEs (assuming 1 km RANGE SAMPLE SPACING) that must overlap in range in order for adjacent azimuths to be identified as part of the same STORM COMPONENTs.

ALGO REF NOs: 5

NAME	SYMBOL	UNITS
THRESHOLD(PATTERN VECTOR(Radial) Number)	TVVN	unitless

DEF: The minimum number of PATTERN VECTORs (Radial) to comprise a feature.

ALGO REF NOs: 29

NAME	SYMBOL	UNITS
THRESHOLD(Pattern Vector Number)	TPN	unitless

DEF: The minimum number of PATTERN VECTORs within a FEATURE (6).

ALGO REF NOs: 24

NAME SYMBOL UNITS

THRESHOLD(Pattern Vector) TPV unitless

DEF: A value which represents the minimum number of PATTERN VECTORs required to build a FEATURE (10.0).

ALGO REF NOs: 2

THRESHOLD(Pixel Fraction) TPF N/A

DEF: The minimum fraction of above-THRESHOLD (dBZe) Pixels required in a LAYER(Previous) correlation box for a correlation-based displacement to be computed for that Box (0.25).

ALGO REF NOs: 34

THRESHOLD(Radial Distance) TRD km

DEF: A value which represents the maximum distance in the radial direction between PATTERN VECTORs in the same FEATURE (0.75), in kilometers.

ALGO REF NOs: 2

THRESHOLD(Range) TRA km

DEF: A variable that represents the range at which long range symmetry criteria take effect, in kilometers (140.0).

ALGO REF NOs: 2

THRESHOLD(Reflectivity-1) THR1 dBZe

DEF: The reflectivity factor considered to be non-zero in the test for isolated SAMPLE VOLUMEs, in dBZe
-minimum
-maximum

ALGO REF NOs: 17

NAME SYMBOL UNITS

THRESHOLD(Score) TSC N/A

DEF: The maximum value below which a STORM is labelled to be a non-hail producer (50).

ALGO REF NOs: 12

THRESHOLD(Segment Length) TSL km

DEF: The minimum length of a STORM SEGMENT (4.2), in kilometers.

ALGO REF NOs: 5,22

THRESHOLD(Symmetry) THY km/hr

DEF: A value for determining symmetry, in km/hr (25.2).

ALGO REF NOs: 7

THRESHOLD(TVS Shear) TTV 1/hr

DEF: The minimum SHEAR(TVS) expected within a TVS FEATURE (180), in 1/hour.

ALGO REF NOs: 26

THRESHOLD(Time Difference) TTD hr

DEF: Maximum time (in hours to the nearest 1/60 hour) to the closest GAGE REPORT (Accumulator) for a valid estimate of accumulation at the ending TIME(Gage Accumulation).

ALGO REF NOs: 20

THRESHOLD(Velocity Number) TVN km/hr

DEF: The number of Doppler velocities used to calculate running averages (5), in km/hr.

ALGO REF NOs: 29

THRESHOLD(Velocity Power)	TPOW	dB

DEF: The received power above which velocities will be processed, in dB (5-10).

ALGO REF NOs: 33

THRESHOLD(Velocity Reflectivity)	TVR	dBZe

DEF: The REFLECTIVITY FACTOR(DBZE) above which Doppler velocities will be processed (15), in dBZe.

ALGO REF NOs: 24,29

THRESHOLD(Velocity)	THV	km/hr

DEF: A RMS velocity threshold (18), in km/hr.

ALGO REF NOs: 7

THRESHOLD(average Doppler Velocity)	TDV	unitless

DEF: The number of average Doppler velocities after a MAXI-MIN needed to perform the "look ahead" capability (7).

ALGO REF NOs: 29

THRESHOLD(dBZe)	THDB	dBZe

DEF: Reflectivity threshold employed in creating binary fields from the two LAYERs, units of dBZe.

ALGO REF NOs: 34

THRESHOLDED PIXEL	ZTPP	N/A

DEF: The thresholded (i.e. zero or one) reflectivity value of a correlation pixel in the current correlation box of LAYER(Previous).
-previous

ALGO REF NOs: 34

THRESHOLDED PIXEL(Current) ZTPC N/A

DEF: The thresholded (i.e. zero or one) reflectivity value of the correlation pixel in LAYER(Current) overlaid by the correlation pixel with value ZTPP in the current correlation box of Layer (Previous) at its current displacement.

ALGO REF NOs: 34

TIME T hr

DEF: The times at which data were collected, in hours.
-current, previous, average, beginning and ending times
-at a particular elevation
-difference
-time of the current and previous scan
-difference between the beginning of the volume scan and the current scan time

ALGO REF NOs: 9,11,12

TIME(Accumulation) TA hr

DEF: The time of an ACCUMULATION SCAN (Hourly) generated by the PRECIPITATION ACCUMULATION [019] algorithm.
-beginning, ending

ALGO REF NOs: 19,20

TIME(Bias Compute) TBC absolute time

DEF: The time that the BIAS was last computed using gage values.
-previous

ALGO REF NOs: 20

NAME SYMBOL UNITS

TIME(Bias Estimation) TBE absolute time

DEF: The time each hour which signals the initiation of the BIAS computation process.

ALGO REF NOs: 20

TIME(Bias Update) TBU absolute time

DEF: The time at which the BIAS was last updated, to at least the nearest 1/60 hour.
-previous

ALGO REF NOs: 20

TIME(Closest Accumulator) TZA absolute time

DEF: The set of times TGbefbeg, TGaftbeg, TGbefend, TGaftend defining the times of occurrence of GAGE REPORTs (Accumulator) closest in time to TGAbeg and TGAend.

ALGO REF NOs: 20

TIME(Current) TCUR hr

DEF: The time at which the volume scan generating LAYER (Current) was collected, units of hr.

ALGO REF NOs: 34

TIME(Difference #2) T2 hr

DEF: The length of time, in hours to the nearest 1/60 hour, that the BIAS has been propagated forward without update using gage data.

ALGO REF NOs: 20

NAME	SYMBOL	UNITS

TIME(Elevation Scan) TES absolute time

DEF: The time at the beginnning and end of each elevation scan.
-beginning, ending

ALGO REF NOs: 17

TIME(End) TEN hr

DEF: Ending time of precipitation at the i-th BOX(1/40th LFM grid) to the nearest 1/1200 hour.

ALGO REF NOs: 30

TIME(Expired) TEX hr

DEF: Time for the i-th BOX(1/40th LM grid) since last precipitation to the nearest 1/1200 hour.

ALGO REF NOs: 30

TIME(Gage Accumulation) TGA absolute time

DEF: The time, each hour.
-When hourly radar and gage accumulations are required by the PRECIPITATION ADJUSTMENT [020] algorithm.
-which signals the end of the hourly gage accumulation period
-ending,beginning

ALGO REF NOs: 19,20

TIME(Gage Interpolation) TGI hr

DEF: The time difference in hours from the TIMEs(Gage Report) closest to TAbeg and TAend, respectively.
-maximum

ALGO REF NOs: 20

NAME SYMBOL UNITS

TIME(Gage Report) TG absolute time

DEF: The time of a particular accumulator gage report.
-before and closest to TGAbeg
-after and closest TGAbeg
-before and closest to TGAend
-after and closest to TGAend

ALGO REF NOs: 20

TIME(Increment Report Accuracy) TIA hr

DEF: Twice the accuracy of the Beginning TIME(Increment Report) of Ending TIME (Increment Report), whichever is the least accurate, in hours to the nearest 1/1200 hr.

ALGO REF NOs: 20

TIME(Increment Report) TI absolute time

DEF: The time of a particular incremental gage report.
-beginning, ending

ALGO REF NOs: 20

TIME(Interpolation) TIP hr

DEF: The maximum period over which a period accumulation scan can be computed using two precipitation rate scans, in hours. Approximately 0.5 hours with a precision of 1/60th hour is required.
-maximum

ALGO REF NOs: 19

TIME(Last Precipitation Detected) TLD absolute time

DEF: The time at which the Precipitation Detection support function last detected precipitation.

ALGO REF NOs: 17,19,21,30

NAME SYMBOL UNITS

TIME(Missing Period) TMP absolute time

DEF: The beginning and ending times of any missing periods between the previous scan time and current scan time. Precise to 1/1200 hr.
-beginning, ending

ALGO REF NOs: 19

TIME(Period) TPE hr

DEF: The beginning and ending times for all ACCUMULATION SCAN(Period) data which are available, in hours. Precise to 1/1200 hr.
-beginning, ending
-minimum

ALGO REF NOs: 19

TIME(Previous) TPRE hr

DEF: The time at which the volume scan generating LAYER (Previous) was collected, units of hr.

ALGO REF NOs: 34

TIME(Propagation) TPR hr

DEF: Time that the BIAS estimates are allowed to propogate before being reset, in hours.
-maximum

ALGO REF NOs: 20

TIME(Reset) TRT hr

DEF: Maximum time allowed for no precipitation before parameters are reset (1-2), in hours.

ALGO REF NOs: 30

NAME	SYMBOL	UNITS
TIME(Scan)	TS	hr

DEF: The beginning time of a scan, in hours.
-reference, previous, current, average
-difference
-time at which a scan was taken, current, previous
-mean observation
-average scan time for the current, previous rate scan
-average difference, average current
-average reference, average projected
-average previous

ALGO REF NOs: 4,7,8,11,12,17,18,19,20,21,30

NAME	SYMBOL	UNITS
TIME(Stamp)	TSP	absolute time

DEF: The time at which the Precipitation Detection support function was last executed.

ALGO REF NOs: 17,21

NAME	SYMBOL	UNITS
TIME(Volume Scan)	TVO	Unitless

DEF: Time at which a volume scan was completed.

ALGO REF NOs: 17

NAME	SYMBOL	UNITS
TIMES(Three Hour Product Generator)	TPG	hr

DEF: A list of times for which 2 km x 2 km PRODUCTs(Three Hour Precipitation) should be generated, in hours, up to once per hour (0-23 inclusive).

ALGO REF NOs: 21

NAME	SYMBOL	UNITS
TOP(Echo)	TOP	km

DEF: The greatest height of an echo computed for a BOX(4 km x 4 km Grid), in kilometers.

ALGO REF NOs: 13

NAME	SYMBOL	UNITS
TRACK VARIANCE(X-direction)	VX	km

DEF: The variance in the STORM position in the X-direction from least squares calculations, in km.

ALGO REF NOs: 8

NAME	SYMBOL	UNITS
TRACK VARIANCE(Y-direction)	VY	km

DEF: The variance in the STORM position in the Y-direction from least squares calculations, in km.

ALGO REF NOs: 8

NAME	SYMBOL	UNITS
TRANSPOSE	TRN	N/A

DEF: The transpose of a vector of a matrix.

ALGO REF NOs: 16

NAME	SYMBOL	UNITS
TURBULENCE	TUR	(km**2/3)/hr

DEF: The turbulence that has been corrected for precipitation effects, in (km**2/3)/hr.

ALGO REF NOs: 23

NAME	SYMBOL	UNITS
TURBULENCE THRESHOLD	TT	(km**2/3)/hr

DEF: The threshold value indicating the onset of turbulence, in (km**2/3)/hr.
-moderate, severe

ALGO REF NOs: 23

NAME	SYMBOL	UNITS
TURBULENCE(Outer Scale)	TOS	km

DEF: The estimated maximum diameter of turbulent eddies for a particular meteorological event, in kilometers.

ALGO REF NOs: 23

TURBULENCE(Uncorrected) TUU (km**4/3)/hr**2

DEF: The turbulence that has not been corrected for precipitation effects, in (km**4/3)/hr**2.

ALGO REF NOs: 23

TVS FEATURE POSITION TVS km & radians

DEF: The position of a TVS FEATURE in range, azimuth and height.

ALGO REF NOs: 26

TYPE(Layer) TYLA N/A

DEF: Indicates which of the available altitude regimes for the LAYER COMPOSITE REFLECTIVITY product is desired for LAYER (Current) and LAYER (Previous).

ALGO REF NOs: 34

VAD RANGE VAD km

DEF: The subset of VAD(Analysis Ranges) used to compute estimates of vertical velocity and divergence, in 1/4 kilometers.

ALGO REF NOs: 7

VAD(Analysis Ranges) VADAR km

DEF: The set of specific slant range(s) for each elevation angle at which horizontal wind estimates are computed. The VAD RANGE is included in the VAD(Analysis Ranges), in 1/4 kilometers.

ALGO REF NOs: 7

NAME SYMBOL UNITS

VARIANCE VNC mm**2

DEF: Variance for that COUNTER(Storm)(in mm**2).
-total guidance value duration
-total guidance value
-sum projected
-temporary projected
-total projected

ALGO REF NOs: 30, 31

VARIANCE ADJUSTMENT FACTOR VAF unitless

DEF: An adjustment factor used to insure that MATRIX (Measurement Covariance) is positive-definite; a dimensionless number less than 1.0 and greater than or equal to 0 (estimated to be 0.5).

ALGO REF NOs: 20

VARIANCE INFLATOR VI Unitless

DEF: A value that reduces the measurement error estimates to account for imperfect prediction of the radar bias itself.

ALGO REF NOs: 20

VECTOR VEC km/hr & radians

DEF: Indicates wind direction and speed. Wind speed is in km/hr and direction is in radians.

ALGO REF NOs: 11

VECTOR(Gage Observation) VGO mm

DEF: The computed hourly gage accumulations for the hour ending with the ending TIME(Gage Accumulation) obtained from the gage reports, in millimeters.

ALGO REF NOs: 20

NAME	SYMBOL	UNITS
VECTOR(Radar Observation)	VRO	mm

DEF: The hourly radar accumulation for the hour ending at the ending TIME(Gage Accumulation). Each value is based on the hourly accumulation scan values of the sample volume directly over the gage and the eight surrounding sample volumes, in millimeters.

ALGO REF NOs: 20

NAME	SYMBOL	UNITS
VELOCITIES(Correlation)	VEL	km/hr, km/hr

DEF: A table containing the coordinates, (km East of radar, km North of radar), of each correlation box's center as well as its velocity estimates (km/hr East, km/hr North).

ALGO REF NOs: 34

NAME	SYMBOL	UNITS
VELOCITY FILTERED	VFL	km/hr

DEF: A VELOCITY(Range Interval Averaged) which has been filtered by the low pass Lanczos filter (in km/hr).
-before, after

ALGO REF NOs: 27

NAME	SYMBOL	UNITS
VELOCITY RANGE(Slant)	VRS	km

DEF: The slant range of a VELOCITY VECTOR, in kilometers.

ALGO REF NOs: 11

NAME	SYMBOL	UNITS
VELOCITY(Azimuthal Derivative)	VA	unitless

DEF: The filtered velocity about which a centered difference approximation of Azimuthal Derivative is to be computed.

ALGO REF NOs: 27

NAME	SYMBOL	UNITS
VELOCITY(Begin Interpolation)	VBI	unitless

DEF: A valid VELOCITY(Range Interval Averaged) (i.e., not equal to DATA(Bad) encountered at a RANGE(Center Interval) after which missing velocity values are encountered as AZIMUTH is incremented.

ALGO REF NOs: 27

VELOCITY(Class Interval)	VELO	km/hr

DEF: The VELOCITY(Doppler) in an INTERVAL(Class), in km/hr.
-maximum
-minimum

ALGO REF NOs: 27

VELOCITY(Doppler Range)	VDR	km/hr

DEF: The Doppler velocity along each radial, in km/hr.
-minimum, maximum

ALGO REF NOs: 26

VELOCITY(Doppler)	VD	km/hr

DEF: Doppler velocities in a SAMPLE VOLUME, in km/hr.
-maximum, minimum
-average
-beginning, ending
-average and maximum difference
-initial, final

ALGO REF NOs: 2,5,7,9,16,22,24,26,27,29,33

VELOCITY(Doppler)DIFFERENCE	VDD	km/hr

DEF: The Doppler velocity difference of a FEATURE, in km/hr.
-average
-maximum

ALGO REF NOs: 29

VELOCITY(East-West) VEW km/hr

DEF: The u (east-west) component of the wind speed, in km/hr.
-average

ALGO REF NOs: 11,16

VELOCITY(End Interpolation) VEI unitless

DEF: A valid VELOCITY(Range Interval) at RANGE(Center Interval) which is encountered just after a missing velocity value as AZIMUTH is incremented.

ALGO REF NOs: 27

VELOCITY(Interpolation) VIN unitless

DEF: A VELOCITY which is estimated from VELOCITYs(Range Interval Average), and is therefore considered to be part of that set of velocities.

ALGO REF NOs: 27

VELOCITY(Interval Center) VELINC km/hr

DEF: The VELOCITY(Doppler) at the center of an INTERVAL (Class), in km/hr.

ALGO REF NOs: 27

VELOCITY(Minimum Number) VNM unitless

DEF: The minimum number of velocities which must be in the INTERVAL(Mode) before an average velocity is computed.

ALGO REF NOs: 27

NAME	SYMBOL	UNITS
VELOCITY(Modified East-West)	VME	km/hr

DEF: The modified component of the east-west wind, in km/hr.

ALGO REF NOs: 16

NAME	SYMBOL	UNITS
VELOCITY(Modified North-South)	VMN	km/hr

DEF: The modified component of the north-south wind, in km/hr.

ALGO REF NOs: 16

NAME	SYMBOL	UNITS
VELOCITY(North-South)	VNS	km/hr

DEF: The v (north-south) component of the wind speed, in km/hr.
-average

ALGO REF NOs: 11,16

NAME	SYMBOL	UNITS
VELOCITY(Number in Interval)	VNUM	unitless

DEF: The number of VELOCITYs (Doppler) which fall into each INTERVAL (Class) over a RANGE INTERVAL. There is one value of VELOCITY (Number in Interval) for each INTERVAL(Class).
-intervals

ALGO REF NOs: 27

NAME	SYMBOL	UNITS
VELOCITY(Precipitation Fall)	VPF	km/hr

DEF: The precipitation fall velocity, in km/hr.

ALGO REF NOs: 7

NAME	SYMBOL	UNITS
VELOCITY(Range Interval Averaged)	VRA	km/hr

DEF: The average velocity over a RANGE INTERVAL (in km/hr).

ALGO REF NOs: 27

VIL SIZE	VS	unitless

DEF: The number of grid boxes (n) covered by echo, i.e.,with integrated liquid water values.

ALGO REF NOs: 15

VIL WEIGHT	VWT	kg/km**2

DEF: The size of the VIL cell (VS) multiplied by the maximum value of VIL (VILSmax) in the cell, in kg/km**2.

ALGO REF NOs: 15

VOLUME(Storm)	VOL	km**3

DEF: The volume of a STORM, in km**3.

ALGO REF NOs: 9

VORTEX TYPE	VTE	unitless

DEF: Designates whether vortices composed of one or more FEATUREs represent a mesocyclone, 3-D shear, or uncorrelated shear.

ALGO REF NOs: 2

WEIGHT	WGT	unitless

DEF: Weight factor (HW1,...,HW7) associated with each of the HAIL IDENTIFIERS (HW1 = 17, HW2 = 15, HW3 = 7, HW4 = 8, HW5 = 20, HW6 = 15, HW7 = 18).

ALGO REF NOs: 12

NAME SYMBOL UNITS

WEIGHT FACTOR(Period Accumulation) WFP hr

DEF: The time between the beginning of a period and the end of a period which covers a particular ACCUMULATION SCAN (Hourly), in hours. Precise to 1/1200 hr.

ALGO REF NOs: 19

WEIGHT(Lanczos Filter) WTLF unitless

DEF: The filtering weights which are determined according to the Lanczos filtering scheme.

ALGO REF NOs: 27

WEIGHT(Normalized) WNDR unitless

DEF: A member of the set of Lanczos filter weights normalized by WEIGHT(Sum).

ALGO REF NOs: 27

WEIGHT(Positive) WPO N/A

DEF: Total weight of all the positive HAIL IDENTIFIERS identified. Weight is an integer.

ALGO REF NOs: 12

WEIGHT(Probable) WPR N/A

DEF: Total weight of all the probable HAIL IDENTIFIERS identified. Weight is an integer

ALGO REF NOs: 12

NAME SYMBOL UNITS

WEIGHT(Sum) WTS unitless

DEF: The sum of the Lanczos Filter weights.

ALGO REF NOs: 27

WIDTH WI km

DEF: The width of a FEATURE, in kilometers.
-average

ALGO REF NOs: 29

WIND (Direction) WDR degrees

DEF: The wind direction, estimated from the SECTORIZED UNIFORM WIND [027] algorithm, valid over a volume of space defined by one set of AZIMUTHS(Filtered Velocities) and a RANGE INTERVAL.

ALGO REF NOs: 27

WIND (Meteorological direction) WME degrees

DEF: The wind direction, in degrees, according to meteorological convention.

ALGO REF NOs: 27

WIND SPEED WSP M/S

DEF: The velocity estimate from the SECTORIZED UNIFORM WIND (027) algorithm, valid over a sector consisting of one set of AZIMUTHS(Filtered Velocities) and a RANGE INTERVAL.

ALGO REF NOs: 27

NAME	SYMBOL	UNITS
X-COEFFICIENT	CVX	km**2

DEF: A coefficient of track variability in the X-direction, in km**2.

ALGO REF NOs: 8

NAME	SYMBOL	UNITS
X-COORDINATE	XI	unitless

DEF: X-coordinate location of i-th BOX (1/40th LFM grid). Values range from -66 to 66 with the radar located within the BOX such that XI = 0.

ALGO REF NOs: 30

NAME	SYMBOL	UNITS
X-DIMENSION	XDIM	unitless

DEF: The integral number of grid locations in the x-direction of the grid as determined by DOMAIN (X Size) and DOMAIN(Resolution).

ALGO REF NOs: 33

NAME	SYMBOL	UNITS
X-EXTENT(Storm)	XEX	km

DEF: The greatest extent of the STORM in the x-direction, in kilometers.

ALGO REF NOs: 28

NAME	SYMBOL	UNITS
X-INDEX	XIN	N/A

DEF: x-index corresponding to the transformation of the DIFFERENCE(Azimuthal) or DIFFERENCE(Radial) values in polar coordinates to the rectangular Cartesian coordinate system used for the shear fields.
-azimuthal
-radial

ALGO REF NOs: 33

X-POSITION X km

DEF: X-position of the CENTROID, in kilometers
-optimum
-lowest, previous, latest, current, highest, average
-forecasted
-first-difference, second-difference
-displacement, midlevel

ALGO REF NOs: 5,9,11,12

X-POSITION(Box) XB km

DEF: X-position of a BOX(1) center, in kilometers.

ALGO REF NOs: 11

X-POSITION(Centroid) XC km

DEF: X-position of the STORM CENTROID (center of mass), in kilometers.
-displacement
-mid level
-highest
-averge, current, forecasted, previous

ALGO REF NOs: 4,5,8

X-POSITION(Feature Center) XFCP km

DEF: X-position of the FEATURE CENTER after conversion from polar to Cartesian coordinates, in kilometers.

ALGO REF NOs: 2

X-POSITION(Sector) XSEC km

DEF: X-position of the center of a SECTOR limited by range, azimuth and elevation, in kilometers.

ALGO REF NOs: 16

X-SPEED(Storm) XS km/hr

DEF: The speed of a STORM in the X-direction, in km/hr.
-previous

ALGO REF NOs: 8,12

Y-COEFFICIENT CVY km**2

DEF: A coefficient of track variability in the Y-direction, in km**2.

ALGO REF NOs: 8

Y-COORDINATE YI unitless

DEF: Y-coordinate location of i-th BOX(1/40 LFM grid). Values range from -66 to 66 with the radar located within the BOX such that YI = 0.

ALGO REF NOs: 30

Y-DIMENSION YDIM unitless

DEF: The integral number of grid locations in the y-direction of the grid as determined by DOMAIN(Y Size) and DOMAIN(Resolution).

ALGO REF NOs: 33

Y-EXTENT(Storm) YEX km

DEF: The greatest extent of the STORM in the y-direction, in kilometers.

ALGO REF NOs: 28

NAME SYMBOL UNITS

Y-INDEX YIND N/A

DEF: Y-index corresponding to the transformation of the DIFFERENCE(Azimuthal) or DIFFERENCE(Radial) values in polar coordinates to the rectangular Cartesian coordinate system used for the shear fields.
-azimuthal
-radial

ALGO REF NOs: 33

Y-INTERCEPT YIN km**2/3

DEF: The y-intercept of the curve that estimates SPECTRUM WIDTH(Normalized Variance), in km**2/3.

ALGO REF NOs: 23

Y-POSITION Y km

DEF: Y-position of a CENTROID, in kilometers.
-optimum
-highest, lowest, current time
-average, current, forecasted
-first-difference, second-difference
-difference
-previous
-displacement, midlevel

ALGO REF NOs: 4,5,9,11,12

Y-POSITION(Box) YB km

DEF: Y-position of a BOX(1) center, in kilometers.

ALGO REF NOs: 11

Y-POSITION(Centroid) YC km

DEF: Y-position of a STORM CENTROID (center of mass), in kilometers.
-displacement
-highest, mid level
-average, current, forecasted, previous

ALGO REF NOs: 4,5,8

Y-POSITION(Feature Center)	YFCP	km

DEF: Y-position of the FEATURE CENTER after conversion from polar to Cartesian coordinates, in kilometers.

ALGO REF NOs: 2

Y-POSITION(Sector)	YSEC	km

DEF: Y-position of the center of a SECTOR limited by range, azimuth and elevation, in kilometers.

ALGO REF NOs: 16

Y-SPEED(Storm)	YS	km/hr

DEF: The speed of a STORM in the Y-direction, in km/hr. -previous

ALGO REF NOs: 8,12

Z-POSITION(Sector)	ZSEC	km

DEF: Z-position of the center of a SECTOR limited by range, azimuth and elevation, in kilometers.

ALGO REF NOs: 16

APPENDIX B

NEXRAD Algorithm Data Dictionary

(sorted by algorithm)

KEY FOR READING
THE NEXRAD ALGORITHM DATA DICTIONARY
(sorted by algorithm)

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY

DEFINITION

NEXRAD REVISION DATA ELEMENTS

SORTED BY NAME

ALGORITHM NUMBER 2 - MESOCYCLONE

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
2-D FEATURE TYPE	TDFT N/A	N/A B	8

Assigns an unique value to indicate that a 2-D FEATURE characterizes a MESOCYCLONE and another if it does not.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
AZIMUTH	AZ N/A	radians A	2

Azimuthal position, in radians.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
AZIMUTH beginning-pattern vector	AZbegpv N/A	radians B,E	5a

Beginning azimuthal position of a PATTERN VECTOR, in radians. Precise to 1.75/10**3 radians.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
AZIMUTH center-feature	AZcenfe N/A	radians B,E	5a

The center azimuth of a 2-dimensional FEATURE, momentum weighted, in radians. Precise to 1.75/10**3 radians.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
AZIMUTH ending-pattern vector	AZendpv N/A	radians B,E	5a

Ending azimuthal position of a PATTERN VECTOR, in radians. Precise to 1.75/10**3 radians.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
AZIMUTH MAXIMUM The largest azimuth found within a FEATURE, in radians. Precise to 1,75/10**3 radians.	AZIMAX N/A	radians B,E	5a
AZIMUTH MINIMUM The smallest azimuth found within a FEATURE, in radians. Precise to 1/10**3 radians.	AZIMIN N/A	radians B,E	5a
DIAMETER(Azimuthal) Azimuthal diameter of a FEATURE, in kilometers. Precise to 1.75/10**4 km.	DAA N/A	km B,E	4a
DIAMETER(Momentum Azimuthal) The momentum weighted azimuthal diameter of a FEATURE, in kilometers. Precise to 1/10**4 km.	DMA N/A	km B,E	4a
DIAMETER(Radial) Radial diameter of a FEATURE, in kilometers. Precise to 1/10**4 km.	DAR N/A	km B,E	4a
DIFFERENCE(Between Feature Centers) The horizontal distance between FEATURE CENTER POSITIONs (at adjacent elevation angles), in kilometers. Precise to 1/10**4 km.	DIF N/A	km B,E	5b

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY	
ELEVATION	PHI# N/A	radians A	2	Elevation angle, in radians. Precise to 1.75/10**3 radians.
FEATURE	FEA N/A	N/A B,E	4a	A set of PATTERN VECTORs which have passed spacial proximity.
FEATURE CENTER POSITION	FCP N/A	N/A B,E	5a	The FEATURE center position in range, elevation and azimuth.
FEATURE EXTREMA	FEX N/A	N/A B,E	4a	A set of four parameters(beginning RANGE(Slant-Feature), ending RANGE(Slant-Feature), beginning feature AZIMUTH and ending Feature AZIMUTH). These are the maximum and minimum AZIMUTHs of its PATTERN VECTOR LIST, and the maximum and minimum ranges from the PATTERN VECTOR LIST.
HEIGHT(Feature Center)	HFC N/A	kilometer B,E	5a	The ELEVATION of a FEATURE center, in kilometers. Precise to 1/10**4 km.
HEIGHT(Feature Center) highest	HFChigh N/A	kilometer B,E	5a	The highest ELEVATION of a FEATURE center (mesocyclone top), in kilometers. Precise to 1/10**4 km.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
HEIGHT(Feature Center) lowest	HFClow N/A	kilometer B,E	 5a

The lowest ELEVATION of a FEATURE center (mesocyclone base), in kilometers. Precise to 1/10**4 km.

INDEX(Azimuth)	j N/A	N/A B	 9

The index for AZIMUTH.

INDEX(Elevation)	i N/A	N/A B	 9

The index for ELEVATION.

MAXIMUM FEATURE DISTANCE	MFD N/A	km B	 4a

A value representing the horizontal distance (formed by projecting one FEATURE diameter into the other's plane) limiting vertical correlation of two FEATUREs at consecutive elevation angles, in kilometers. Precise to 1/10**4 km.

MESOCYCLONE ID	MESID N/A	N/A E	 7

An ID assigned to a mesocyclone when the MESOCYCLONE Algorithm identifies a mesocyclone.

MOMENTUM(Angular)	M N/A	km**2/hr B,E	 4a

Angular momentum, in km**2/hr. Precise to 3.6 x 1/10**5 km/hr.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
MOMENTUM(Angular) average	Mavg N/A	km**2/hr B,E	 4a

Average MOMENTUM(Angular) determined from the PATTERN VECTORs comprising a FEATURE, in km**2/hr. Precise to 3.6 x 1/10**5 km/hr.

PATTERN VECTOR	PVE N/A	N/A B	 4a

A vector which is formed when a run of increasing Doppler velocity ends. A PATTERN VECTOR contains seven components: the slant range, the azimuth angles at both ends of the run, the Doppler velocities that correspond to those azimuth angles at the slant range, and the SHEAR(Tangential) and MOMENTUM(Angular).

PATTERN VECTOR LIST	PVL	N/A D	 4a

The set of all PATTERNS VECTORs in a FEATURE.

PI	PI# 3.1416	unitless B	 3

A mathematical constant (3.1416), unitless.

POSITION MAXIMUM SHEAR(Tangential)	PMST N/A	km,radians,radians E	 5a

The RANGE(Slant), beginning pattern vector AZIMUTH and ending pattern vector AZIMUTH where the maximum SHEAR (Tangential) is found in a feature classified as a mesocyclone vortex, in kilometers, radians and radians. Precise to 1/10**4 kilometers, 1.75 1/10**3 radians.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
POSITION(Mesocyclone)	PM	km, radians, radians	
	N/A	E	5a

The mesocyclone position in range, azimuth and elevation angle, in kilometers, radians and radians. Precise to 1/10**4 kilometers, 1.75/10**3 radians.

RADIUS(Earth)	RE	km	
	6371	A	7

The radius of the Earth (6371), in kilometers. Precise to 1/10**4 km.

RANGE(Slant Pattern Vector)	RSPV	km	
	N/A	B	5a

The RANGE(Slant) of a PATTERN VECTOR, in kilometers. Precise to 1/10**4 kilometers.

RANGE(Slant)	RS	km	
		A	1

The slant range to the center of a SAMPLE VOLUME, in kilometers. Precise to 1/10**4 km.

RANGE(Slant-Feature) beginning	RSFEbeg	km	
	N/A	B	5a

The beginning slant range of a FEATURE, in kilometers. Precise to 1/10**4 km.

RANGE(Slant-Feature) center	RSFEcen	km	
	N/A	B	5a

The slant range of a FEATURE center, in kilometers. Precise to 1/10**4 km.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY	
RANGE(Slant-Feature) ending	RSFEend N/A	km B	5a	The ending slant range of a FEATURE, in kilometers. Precise to 1/10**4 km.
RATIO(Diameter)	ROD N/A	unitless B	4a	The ratio of the azimuthal diameter to the radial diameter of a FEATURE.
RATIO(Momentum Diameter)	RMD N/A	unitless B	4a	The ratio of the momentum weighted azimuthal diameter to the radial diameter of a FEATURE.
SAMPLE VOLUME	SV N/A	N/A A	1	A data sample volume whose dimensions are 1 degree in azimuth, 0.25 km in range, and 1 degree in depth (perpendicular to the radar beam).
SHEAR(Tangential)	SRT N/A	1/hr B	4a	The change in Doppler velocity for a PATTERN VECTOR divided by its length, 1/hr. Precise to 3600 1/hr.
SHEAR(Tangential) average	SRTavg N/A	1/hr B	4a	The average SHEAR (Tangential) of all the PATTERN VECTORs in a FEATURE, in 1/hr. Precise to 3600 1/hr.

NAME	SYMBOL	VALUE	UNITS	CLASS	CATEGORY	
SHEAR(Tangential) maximum	SRTmax	N/A	1/hr	B	4a	The maximum SHEAR (Tangential) of all the PATTERN VECTORs in a FEATURE, in 1/hr. Precise to 3600 1/hr.
SHEAR(Tangential) maximum-average	SRTmaxavg	N/A	1/hr	B	4a	The largest of all the SHEAR (Tangentials), in 1/hr. Precise to 3600 1/hr.
SPEED(Rotational) average	SPRavg	N/A	km/hr	C	4a	Half the momentum weighted diameter of a feature times the average SHEAR(Tangential), in km/hr. Precise to .36 km/hr.
TENDENCY	TCY	N/A	unitless	B	4a	The trend in Doppler velocities (increasing (+), decreasing (-)) in the azimuthal direction.
THRESHOLD(Far Maximum Ratio)	TFMX	4.0	unitless	A	3	A maximum value which represents the upper bound of a range of values related to the ratio of radial and azimuthal diameters of a FEATURE at ranges further than THRESHOLD(Range) (4.0).
THRESHOLD(Far Minimum Ratio)	TFMN	1.6	unitless	A	3	A minimum value which represents the lower bound of a range of values related to the ratio of radial and azimuthal diameters of a FEATURE at ranges further than THRESHOLD(Range) (1.6).

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
THRESHOLD(Feature Height)	TFH 8	km A	 3

A value that represents the maximum height of possible mesocyclone FEATUREs (8 km), in kilometers.

THRESHOLD(High Momentum)	THM 540.0	km**2/hr A	 3

A value which represents the minimum magnitude of angular momentum expected in a mesocyclone in the presence of low shear, in 540.0 km**2/hr.

THRESHOLD(Low Momentum)	TLM 180.0	km**2/hr A	 3

A value which represents the minimum magnitude of angular momentum in a mesocyclone, in 180.0 km**2/hr.

THRESHOLD(Maximum Ratio)	TMR 2.0	unitless A	 3

A maximum value which represents the upper bound of a range of values related to the ratio of radial and azimuthal diameters of a FEATURE at ranges closer than THRESHOLD(Range) (2.0).

THRESHOLD(Mesocyclone Azimuth)	TMA 0.034	radians A	 3

A value that represents the maximum tangential seperation of PATTERN VECTORs to be considered part of the same FEATURE (0.034), in radians.

THRESHOLD(Mesocyclone-High Shear)	TMHS 14.4	1/hr A	 3

A value which represents the minimum magnitude of shear expected in a mesocyclone in the presence of low angular momentum, in 14.4 1/hr.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
THRESHOLD(Mesocyclone-Low Shear)	TMLS 7.2	1/hr A	3

A value which represents the minimum magnitude of shear expected in a mesocyclone, in 7.2 1/hour.

THRESHOLD(Minimum Ratio)	TRM 0.5	unitless A	3

A minimum value which represents the lower bound of a range of values related to the ratio of radial and azimuthal diameters of a FEATURE at ranges closer than THRESHOLD(Range) (0.5).

THRESHOLD(Pattern Vector)	TPV 10.0	unitless A	3

A value which represents the minimum number of PATTERN VECTORs required to build a FEATURE (10.0).

THRESHOLD(Radial Distance)	TRD 0.75	km A	3

A value which represents the maximum distance in the radial direction between PATTERN VECTORs in the same FEATURE (0.75), in kilometers.

THRESHOLD(Range)	TRA 140.0	km A	3

A variable that represents the range at which long range symmetry criteria take effect, in kilometers (140.0).

VELOCITY(Doppler)	VD N/A	km/hr A	1

Doppler velocities in a SAMPLE VOLUME, in km/hr. Precise to .36 km/hr.

NAME	SYMBOL	UNITS	
	VALUE	CLASS	CATEGORY

VELOCITY(Doppler)	VDbeg	km/hr	
beginning	N/A	B	4a

The Doppler velocity at the beginning of a PATTERN VECTOR, in km/hr. Precise to .36 km/hr.

VELOCITY(Doppler)	VDend	km/hr	
ending	N/A	B	4a

The Doppler velocity at the end of a PATTERN VECTOR, in km/hr. Precise to .36 km/hr.

VORTEX TYPE	VTY	unitless	
	N/A	B,E	8

Designates whether vortices composed of one or more FEATUREs represent a mesocyclone, 3-D shear, unitless.

X-POSITION(Feature Center)	XFCP	km	
	N/A	B	5a

X-position of the FEATURE CENTER after conversion from polar to Cartesian coordinates, in kilometers. Precise to 1/10**4 kilometers.

Y-POSITION(Feature Center)	YFCP	km	
	N/A	B	5b

Y-position of the FEATURE CENTER after conversion from polar to Cartesian coordinates, in kilometers. Precise to 1/10**4 kilometers.

NEXRAD REVISION DATA ELEMENTS

SORTED BY NAME

ALGORITHM NUMBER 4 - STORM TRACKING

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
BEST X-POSITION	BXP N/A	km A	5a

An X-position based on either the SPEED(Mean) or previous SPEED (Storm), in kilometers. Precise to 1/10**4 kilometers.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
BEST X-SPEED	BXS N/A	km/hr A	5a

The SPEED in the X-direction, in km/hr. Precise to .36 km/hr.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
BEST Y-POSITION	BYP N/A	km A	5a

A Y-Position based on either the SPEED (Mean) or previous SPEED (Storm), in kilometers. Precise to 1/10**4 kilometers.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
BEST Y-SPEED	BYS N/A	km/hr A	5a

The SPEED in the Y-direction, in km/hr. Precise to .36 km/hr.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
CORRELATION(Distance)	CD N/A	km B	4b

Defines the distance used (between centroids) to determine if a current storm is the same as one of the storms identified earlier, in kilometers. Precise to 1/10**4 kilometers.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
CORRELATION(Speed)	CS 120	km/hr A	3

Speed used to compute the CORRELATION(Distance), in km/hr. Precise to .36 km/hr.

CORRELATION(Table)	CT N/A	N/A A,D	10

A data set used to keep track of the positions of correlated STORMs.

DIFFERENCE(Best Position)	BPD N/A	km A	5a

The distance between the best position point as computed by the SPEED (Mean) and direction or STORM (Speed) and direction and the current position of the STORM centroid, in kilometers. Precise to 1/10**4 kilometers.

DIRECTION(Best Position)	DBP N/A	radians A	5a

The direction towards which a STORM is moving, in radians. Precise to 1/10**3 radians.

DIRECTION(Limit)	DLM PI#/2	radians A	5a

The maximum deviation from the DIRECTION (Best Position) that a STORM is allowed in order to be considered as the same STORM at a previous time (PI#/2), in radians. Precise to 1/10**3 radians.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY	
DIRECTION(Mean)	DMN N/A	radians A	5a	The direction from which a STORM is moving. This is either obtained from the average of the DIRECTION (Storm) or the operator input, in radians. Precise to 1/10**3 radians.
DIRECTION(Minus)	DM N/A	radians A	5a	The DIRECTION (Best Position) minus the DIRECTION (Limit), in radians. Precise to 1/10**3 radians.
DIRECTION(PLUS)	DP N/A	radians A	5a	The DIRECTION (Best Position) plus the DIRECTION (Limit), in radians. Precise to 1/10**3 radians.
DIRECTION(Storm Position)	DSP N/A	radians A	5a	The direction between centroids at the current time and centroids at the previous time, in radians. Precise to 1/10**3 radians.
MASS(Storm)	MST N/A	kg A	5a	The mass weighted volume of a STORM, in kilograms. Precise to 1/10**3 kilograms.
MASS(Storm) current	MSTcur N/A	kg A	5a	The mass weighted volume of a STORM at the current time, in kilograms. Precise to 1/10**3 kilograms.

NAME	SYMBOL	UNITS	
	VALUE	CLASS	CATEGORY

MASS(Storm)	MSTpre	kg	
previous	N/A	A	5a

The mass weighted volume of a STORM at the previous time, in kilograms. Precise to 1/10**3 kilograms.

MASS-VOLUME RATIO	MVR	unitless	
	N/A	A	5a

The ratio of the STORM's mass volume at the current time, to the STORM's mass volume at the previous time. The value is always 1 or greater.

RATIO(Minimum)	RATM	unitless	
	10	B	3

The minimum MASS-VOLUME RATIO needed before the distance correlation will be made. This is a site-adaptable parameter with the current implemented NSSL value being 10.

SPEED(Mean)	SPM	km/hr	
	N/A	A	5a

The SPEED(Storm) either obtained from the average of SPEED(Storm) or operator input, in km/hr. If neither is available, a default value of 0 will be used. Precise to .36 km/hr.

SPEED(Minimum)	SPDM	km/hr	
	2	B	3

The minimum SPEED a STORM must have in order for a 360 degree search to be conducted to find its next position (for STORMs moving faster than this SPEED, a smaller search window is used) (2), in km/hr. Precise to .36 km/hr.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY	
STORM	ST N/A	N/A A	7	A three dimensional region composed of STORM COMPONENTs characterized by reflectivity values above a given threshold, ordered by mass weighted volume.
TIME(Scan)	TS N/A	hr A	6a	The beginning time of a scan, in hours. Precise to 1/3600 hr.
TIME(Scan) current	TScur N/A	hr A	6a	The current time at which data is collected, in hours. Precise to 1/3600 hr.
TIME(Scan) difference	TSdif N/A	hr B	6b	Time difference between scans, in hours. Precise to 1/3600 hr.
TIME(Scan) previous	TSpre N/A	hr A	6a	The previous time at which data was collected, in hours. Precise to 1/3600 hr.
X-POSITION(Centroid)	XC N/A	km D	5a	X-position of a STORM CENTROID (center of mass), in kilometers. Precise to 1/10**4 kilometers.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
X-POSITION(Centroid) current	XCcur N/A	km A	5a

X-position of a STORM CENTROID (center of mass), at the current time, in kilometers. Precise to 1/10**4 kilometers.

X-POSITION(Centroid) difference	XCdif N/A	km A	5b

The difference between X-POSITION(Centroid) of a storm at the current time and X-POSITION(Centroid) of a storm at the previous time.

X-POSITION(Centroid) previous	XCpre N/A	km A	5a

X-position of a STORM CENTROID (center of mass), at the previous time, in kilometers. Precise to 1/10**4 kilometers.

Y-POSITION(Centroid)	YC N/A	km D	5a

Y-position of a STORM CENTROID (center of mass), in kilometers. Precise to 1/10**4 kilometers.

Y-POSITION(Centroid) current	YCcur N/A	km A	5a

Y-position of a STORM CENTROID (center of mass), at the current time, in kilometers. Precise to 1/10**4 kilometers.

Y-POSITION(Centroid) difference	YCdif N/A	km B	5b

The difference in Y-POSITION (Centroid) of a storm at the current time and Y-position (Centroid) of a storm at the previous time.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
Y-POSITION(Centroid) previous	YCpre N/A	km A	5a

Y-position of a storm centroid (center of mass), at the previous time, in kilometers. Precise to 1/10**4 kilometers.

NEXRAD REVISION DATA ELEMENTS

SORTED BY NAME

ALGORITHM NUMBER 5 - STORM CENTROIDS

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
ADJACENCY	ADJ N/A	unitless B	3

The number of adjacent azimuths required to define a STORM COMPONENT.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
ADJACENCY minimum	ADJmin 1	unitless B	3

The minimum number of adjacent azimuths required to define a STORM COMPONENT(1).

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
AREA(Storm Component)	A N/A	km**2 E	8

Area of a STORM COMPONENT at a particular ELEVATION, in km**2. Precise to 1/10**6 kilometers **2.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
AZIMUTH	AZ N/A	radians A	2

Azimuthal position, in radians. Precise to 1/10**3 radians.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
AZIMUTH RANGE(Slant) beginning	ARSbeg N/A	km A	5a

The average slant range for the first azimuth of a STORM COMPONENT, in kilometers. Precise to 1/10**4 kilometers.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
AZIMUTH RANGE(Slant) ending	ARSend N/A	km A	5a

The average slant range for the last azimuth of a STORM COMPONENT, in kilometers. Precise to 1/10**4 kilometers.

AZIMUTH(Delta)	AZDE N/A	radians B	4a

The azimuthal increment, in radians. Precise to 1/10**3 radians.

CENTROID DISTANCE	CED N/A	km B	5A

The distance or radius of a STORM COMPONENT, in kilometers. Precise to 1/10**4 kilometers.

ELEVATION	PHI# N/A	radians A	2

Elevation angle, in radians. Precise to 1/10**3 radians.

HEIGHT(Storm Component-Centroid)	HSCC N/A	km C	5a

Height of the centroid of a STORM COMPONENT at a particular ELEVATION above the ground, in kilometers. Precise to 1/10**4 kilometers.

HEIGHT(Storm Component-Centroid) difference	HSCCdif N/A	km B	5b

Height difference between centroids of STORM COMPONENTs at two separate ELEVATIONs, in kilometers. Precise to 1/10**4 kilometers.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
HEIGHT(Storm)	HSTO N/A	km A	10

The height of a STORM CENTROID (center of mass), in kilometers. Precise to 1/10**4 kilometers.

INDEX(Elevation)	i N/A	N/A B	9

The index for ELEVATION.

MASS WEIGHTED LENGTH	MWL N/A	kg/km**2 D	8

Mass density weighted length of a STORM SEGMENT, in kg/km**2.

MASS WEIGHTED LENGTH SQUARED	MWS N/A	kg/km A	8

Mass density weighted length squared of a STORM SEGMENT, in kg/km.

MASS(Storm Component)	MSC N/A	kg/km B	8

The mass weighted area of a STORM COMPONENT, in kg/km.

MASS(Storm)	MST N/A	kg B	8

The mass weighted volume of a STORM, in kilograms. Precise to 1/10**3 kilograms.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY	
MAXIMUM CENTROID DISTANCE	MCD N/A	km B	4a	The maximum centroid distance for the STORM COMPONENT at the previous or next previous elevation, in kilometers. Precise to 1/10**4 kilometers.
PI	PI# 3.1416	unitless B	3	A mathematical constant (3.1416), unitless.
POSSIBLE COMPONENT	PSTC N/A	N/A D	10	A group of SAMPLE VOLUMEs, which are possibly contiguous with respect to range (STORM SEGMENTs) and azimuth, at the same elevation angle. More than one may exist at a given elevation.
RADIUS CORRECTION(Earth)	RCOE 1.21	unitless A	7	The factor by which the RADIUS(Earth) is multiplied to account for refraction of the radar beam (1.21).
RADIUS(Earth)	RE 6371	km A	7	The radius of the Earth (6371), in kilometers. Precise to 1/10**4 kilometers.
RANGE SAMPLE SPACING	RSS 1	km A	2	The difference in ranges between two adjacent SAMPLE VOLUMEs along a radial, i.e., the length of a SAMPLE VOLUME(1), in kilometers. Precise to 1/10**4 kilometers.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
RANGE(Slant-Storm Segment)	RSSS N/A	km A	5a

The slant range (center of SAMPLE VOLUME) of a STORM SEGMENT, in kilometers. Precise to 1/10**4 kilometers.

RANGE(Slant-Storm Segment) beginning	RSSSbeg N/A	km A	5a

The beginning slant range (center of SAMPLE VOLUME) of a STORM SEGMENT, in kilometers. Precise to 1/10**4 kilometers. Precise to 1/10**4 kilometers.

RANGE(Slant-Storm Segment) ending	RSSSend N/A	km A	5a

The ending slant range (center of SAMPLE VOLUME) of a STORM SEGMENT, in kilometers. Precise to 1/10**4 kilometers.

REFLECTIVITY FACTOR(DBZE)	DBZE N/A	dBZe A	1

The effective radar reflectivity factor of a SAMPLE VOLUME, in dBZe.

REFLECTIVITY FACTOR(DBZE) maximum	DBZEmax N/A	dBZe C	1

The maximum effective radar reflectivity factor, in dBZe.

REFLECTIVITY(Storm Component)	ZSC N/A	dBZe A	1

Effective reflectivity value detected in an individual STORM COMPONENT, in dBZe.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
REFLECTIVITY(Storm Component) maximum	ZSCmax N/A	dBZe C	1

Maximum effective reflectivity value detected in an individual STORM COMPONENT, in dBZe.

SHAPE(AXIS2)	SAX2 N/A	km A	5a

The second axis of an ellipse defined by the SHAPE (Length) calculated from the area of the STORM COMPONENT, in kilometers. Precise to 1/10**4 kilometers.

SHAPE(Ellipticity)	SELP N/A	N/A A	5a

The ratio of the axis length of the ellipse defined by SHAPE(Length) and SHAPE(AXIS2). A dimensionless quantity ranging from 0 to 1.

SHAPE(Length)	SLEN N/A	N/A A	5a

The distance between the points located by the beginning AZIMUTH RANGE(Slant) and the first azimuth of a STORM COMPONENT, and the ending AZIMUTH RANGE(Slant) and the last azimuth of a STORM COMPONENT, in kilometers. Precise to 1/10**4 kilometers.

SHAPE(Orientation)	SORI N/A	radians A	5a

The orientation of the ellipse represented by SHAPE (Length) and SHAPE(AXIS2), in radians. Precise to 1/10**3 radians.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
SPECTRUM WIDTH	W	km/hr	
	N/A	C	1

Spectrum width value, in km/hr. Precise to .36 km/hr.

SPECTRUM WIDTH	Wmax	km/hr	
maximum	N/A	A	1

Maximum spectrum width value, in km/hr. Precise to .36 km/hr.

STORM	ST	N/A	
	N/A	E	7

A three-dimensional region composed of STORM COMPONENTs characterized by reflectivity values above a given threshold, ordered by mass weighted volume.

STORM	STuno	N/A	
unordered	N/A	D	7

A three-dimensional region composed of STORM COMPONENTs characterized by reflectivity values above a given threshold, unordered by mass weighted volume.

STORM COMPONENT	STC	N/A	
	N/A	C	7

A group of SAMPLE VOLUMEs, contiguous with respect to range (STORM SEGMENTs) and azimuth, at the same elevation angle. More than one may exist at a given elevation.

STORM SEGMENT	SMT	N/A	
	N/A	A	7

A set of numbered, contiguous SAMPLE VOLUMEs along a radial identified by reflectivity factor values above a specified threshold. A STORM SEGMENT includes: beginning RANGE(Slant), ending RANGE(Slant), maximum REFLECTIVITY FACTOR(DBZE), most minimum and most maximum VELOCITY (Doppler), maximum SPECTRUM WIDTH, AZIMUTH and ELEVATION angle.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
THRESHOLD(Overlap)	TOV 2	unitless A	3

Minimum number of SAMPLE VOLUMEs (assuming 1 km RANGE SAMPLE SPACING) that must overlap in range in order for adjacent azimuths to be identified as part of the same STORM COMPONENTs.

THRESHOLD(Segment Length)	TSL 4.2	km A	3

The minimum length of a STORM SEGMENT (4.2), in kilometers. Precise to 1/10**4 kilometers.

VELOCITY(Doppler)	VD N/A	km/hr A	1

Doppler velocities in a data SAMPLE VOLUME, in km/hr. Precise to .36 km/hr.

VELOCITY(Doppler) maximum	VDmax N/A	km/hr C	1

The maximum Doppler velocity value, in km/hr. Precise to .36 km/hr.

X-POSITION	X N/A	km C	5a

X-position of the CENTROID, in kilometers. Precise to 1/10**4 kilometers.

X-POSITION first-difference	Xdif1 N/A	km B	5b

X-position difference between STORM COMPONENTs at adjacent ELEVATIONs, in kilometers. Precise to 1/10**4 kilometers.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
X-POSITION second-difference	Xdif2 N/A	km B	5b

X-position difference between STORM COMPONENTs at non-adjacent ELEVATIONs, in kilometers. Precise to 1/10**4 kilometers.

X-POSITION(Centroid)	XC N/A	km A	10

X-position of the STORM CENTROID (center of mass), in kilometers. Precise to 1/10**4 kilometers.

Y-POSITION	Y N/A	km B	5a

Y-position of the CENTROID, in kilometers. Precise to 1/10**4 kilometers.

Y-POSITION first-difference	Ydif1 N/A	km B	5b

Y-position difference between STORM COMPONENTs at adjacent ELEVATIONs, in kilometers. Precise to 1/10**4 kilometers.

Y-POSITION second-difference	Ydif2 N/A	km B	5b

Y-position difference between STORM COMPONENTs at non-adjacent ELEVATIONs, in kilometers. Precise to 1/10**4 kilometers.

Y-POSITION(Centroid)	YC N/A	km A	10

Y-position of the STORM CENTROID (center of mass), in kilometers. Precise to 1/10**4 kilometers.

NEXRAD REVISION DATA ELEMENTS

SORTED BY NAME

ALGORITHM NUMBER 6 - VERTICALLY-INTEGRATED LIQUID WATER

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
AZIMUTH	AZ	radians	
	N/A	A	2

Azimuthal position, in radians. Precise to 1/10**3 radians.

BEAM WIDTH	BW	radians	
	.017	A	2

The angular width of the radar beam between the half-power points, in radians (.017). Precise to 1/10**3 radians.

BOX(4 km X 4 km Grid)	BX4	N/A	
	N/A	D	4b

Square grid boxes which are 4 km on a side and cover ranges from 0 to 230 km.

CATEGORIES	C	unitless	
	N/A	A	4b

Categorized effective reflectivity factor data for each SAMPLE VOLUME.

DEPTH(Beam)	DB	km	
	N/A	B	2

The depth of radar beam as a function of range for each grid box, in kilometers. Precise to 1/10**4 kilometers.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
ELEVATION	PHI# N/A	radians A	 2

Elevation angle, in radians. Precise to 1/10**3 radians.

LIQUID WATER	LW N/A	kg/km**3 B	 8

The liquid water content for a particular value of reflectivity, in kg/km**3.

LIQUID WATER maximum	LWmax N/A	kg/km**3 C	 8

The maximum liquid water content found within a grid box, in kg/km**3.

LIQUID WATER(Integrated)	VIL N/A	kg/km**2 E	 8

Integrated liquid water values (per grid box) for a column within a STORM, in kg/km**2.

LIQUID WATER(Integrated) maximum	VILmax N/A	kg/km**2 D	 8

The maximum LIQUID WATER(Integrated) value in the scanning region, in kg/km**2.

LIQUID WATER(Integrated) partial	VILpar N/A	kg/km**2 A	 10

The portion of the LIQUID WATER(Integrated) in a column which is detected at a particular elevation (per grid box) within a storm, in kg/km**2.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
RADIUS(Earth)	RE 6371	km A	7

The radius of the Earth (6371), in kilometers. Precise to 1/10**4 kilometers.

RANGE(Horizontal)	RH N/A	km B	5a

The horizontal range, in kilometers. Precise to 1/10**4 kilometers.

RANGE(Slant)	RS N/A	km A	5a

The slant range to the center of a SAMPLE VOLUME, in kilometers. Precise to 1/10**4 kilometers.

REFLECTIVITY FACTOR(ZE)	ZE N/A	mm**6/m**3 A	1

The effective radar reflectivity factor of a SAMPLE VOLUME, in mm**6/m**3.

NEXRAD REVISION DATA ELEMENTS

SORTED BY NAME

ALGORITHM NUMBER 7 - VELOCITY-AZIMUTH DISPLAY

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
ALTITUDE	ALT N/A	km B	4a

The height above sea level, in kilometers. Precise to 0.1 kilometers.

AREA(Surface Change)	ASC N/A	km B	4a

The rate of change of AREA(Surface) with respect to height, in km**2/km or kilometers. Precise to 0.1 kilometers.

AREA(Surface)	AS N/A	km**2 B	4a

The surface area in the plane above the radar bounded by the VAD analysis range, in km**2.

AZIMUTH	AZ N/A	radians A	2

Azimuthal position, in radians. Precise to 1/10**3 radians.

COEFFICIENT(Fourier, #1)	CF1 N/A	km/hr C	4a

The Fourier series coefficient #1 that allows for the best possible approximation of a function, in km/hr. Precise to 0.1 km/hr.

NAME SYMBOL UNITS
VALUE CLASS CATEGORY

COEFFICIENT(Fourier, #2) CF2 km/hr
N/A C 4a

The Fourier series coefficient #2 that allows for the best possible approximation of a function, in km/hr. Precise to 0.1 km/hr.

COEFFICIENT(Fourier, #3) CF3 km/hr
N/A C 4a

The Fourier series coefficient #3 that allows for the best possible approximation of a function, in km/hr. Precise to 0.1 km/hr.

DENSITY(Atmospheric Gradient) DRHO# kg/km**4
N/A A 4b

A set of density gradient values at each altitude, in kg/km**4. Precise to 10**6kg/km**4.

DENSITY(Atmospheric) RHO# kg/km**3
N/A A 4b

A set of density values for each altitude, in kg/km**3. Precise to 10**6kg/km**3.

DIRECTION(Wind) DW radians
N/A C 8

The horizontal direction from which the wind is flowing, in radians. Precise to 1/10**3 radians.

DISTANCE(Earth Center) DEC km
N/A B 4a

The distance from the Earth center, in kilometers. Precise to 0.1 kilometers.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY	
DIVERGENCE(Horizontal)	DIV N/A	1/hr C	B	Horizontal divergence, in 1/hour. Precise to .01 1/hr.
ELEVATION	PHI# N/A	radians C	2	Elevation angle, in radians. Precise to 1/10**3 radians.
FIT	FIT N/A	km/hr A	4b	The Doppler velocity value at a given azimuth angle on the Fourier least squares fitted curve, in km/hr. Precise to 0.1 km/hr.
FIT TESTS	FT 2	N/A C	4b	The number of times the fit test procedure is to be run (2).
HEIGHT (VAD Wind Estimate)	HVAD N/A	km B	C	The height above the ground level from which data was collected, in kilometers. Precise to 0.1 kilometers.
HEIGHT(Radar)	HR N/A	km A	5a	The radar height above sea level, in kilometers. Precise to 0.1 kilometers.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY	
INDEX(Azimuth)	j N/A	N/A B	9	The index for AZIMUTH.
INDEX(Elevation)	i N/A	N/A B	9	The index for ELEVATION.
NUMBER(Data Points)	ND unitless	unitless C	4a	The number of non-missing data points between THRESHOLD (Begin Azimuth) and THRESHOLD(End Azimuth) that went into the Fourier least squares fitting.
PI	PI# 3.1416	unitless B	10	A mathematical constant (3.1416), unitless.
RADIUS(Earth)	RE 6371	km A	7	The radius of the Earth (6371), in kilometers. Precise to 1/10**4 kilometers.
RANGE(Slant)	RS N/A	km C	2	The slant range to the center of a SAMPLE VOLUME, in kilometers. Precise to 0.1 kilometers.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY	
REFLECTIVITY FACTOR(ZE)	ZE N/A	mm**6/m**3 A	1	The effective radar reflectivity factor of a SAMPLE VOLUME, in mm**6/m**3.
ROOT MEAN SQUARE	RMS N/A	km/hr C	4a	The square root of mean squared deviations of Doppler velocities from a Fourier least-squares fit curve, in km/hr. Precise to 0.1 km/hr.
SPEED(Horizontal Wind)	SHW N/A	km/hr C	8	Horizontal wind speed, in km/hr. Precise to 0.1 km/hr.
SPEED(Vertical Wind Change)	SVC N/A	1/hr B	4a	The rate of change of the vertical wind speed at a specific altitude, in (km/hr)/km or 1/hr.
SPEED(Vertical Wind)	SVW N/A	km/hr C	8	The vertical wind speed (positive upward), in km/hr. Precise to 1/10**3 km/hr.
SPEED(Wind)	SPW N/A	km/hr C	8	The horizontal wind speed not corrected for the elevation angle of measurement, in km/hr. Precise to 0.1 km/hr.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
SYMMETRY	SYMM N/A	N/A B	10

A flag value that is positive if the absolute value of COEFFICIENT(Fourier, #1) is less than THRESHOLD (Symmetry) and the absolute value of COEFFICIENT (Fourier, #1) minus SPEED(Wind) is less than or equal to zero.

THRESHOLD(Begin Azimuth)	TBZ N/A	radians A	3

Starting azimuth for VAD analysis, in radians.

THRESHOLD(Data Points)	TDP 25	unitless A	3

The minimum number of data points allowed for the Fourier least squares fitting, unitless (25).

THRESHOLD(End Azimuth)	TEZ N/A	radians A	3

Ending azimuth for VAD analysis, in radians.

THRESHOLD(Symmetry)	THY 25.2	km/hr A	4b

A value for determining symmetry, in km/hr (25.2).

THRESHOLD(Velocity)	THV 18	km/hr A	3

A RMS velocity threshold (18), in km/hr.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY	
TIME(Scan)	TS N/A	hr A	6a	The beginning time of a scan, in hours. Precise to 1/3600 hr.
VAD RANGE	VAD N/A	km A	3	The subset of VAD(Analysis Ranges) used to compute estimates of vertical velocity and divergence. in 1/4 kilometers.
VAD(Analysis Ranges)	VADAR N/A	km A	7	The set of specific slant range(s) for each elevation angle at which horizontal wind estimates are computed. The VAD RANGE is included in the VAD(Analysis Ranges), in 1/4 kilometers.
VELOCITY(Doppler)	VD N/A	km/hr A	1	Doppler velocities in a SAMPLE VOLUME, in km/hr. Precise to 0.1 km/hr.
VELOCITY(Precipitation Fall)	VPF N/A	km/hr B	4a	The precipitation fall velocity, in km/hr. Precise to 0.1 km/hr.

NEXRAD REVISION DATA ELEMENTS

SORTED BY NAME

ALGORITHM NUMBER 8 - STORM FORECAST

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
ALLOWABLE ERROR	AER N/A	km A	3

The maximum error in the track of a STORM allowed during the ERROR INTERVAL, in kilometers. Precise to 1/10**4 kilometers.

CORRELATION(Table)	CT N/A	N/A A	5a

A data set used to keep track of the positions of correlated STORMs.

DIRECTION(Storm)	DS N/A	radians C	8

Direction from which a STORM is moving, in radians. Precise to 1/10**3 radians.

ERROR INTERVAL	EI .25	hr A	3

The amount of time upon which the ALLOWABLE ERROR was based, in hours. Precise to 1/3600 hr.

FORECAST ERROR	FE N/A	km C	4b

The departure of the current STORM position from the position forecasted for that STORM at the previous time, in km. Precise to 1/10**4 km.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
FORECAST ERROR mean	FEmean N/A	km C	4b

The average FORECAST ERROR of a STORM (refers to a single Storm over its entire life-time), in kilometers. Precise to 1/10**4 kilometers.

FORECAST INTERVAL	FI N/A	hr A	3

A set of time intervals for which centroid positions may be projected into the future, in hours. Precise to 1/3600 hr.

PERMISSIBLE ERROR	PE N/A	km B	4a

The maximum error allowed in the forecast of a STORM for each forecast interval, in kilometers. Precise to 1/10**4 kilometers.

SPEED(Storm)	SS N/A	km/hr C	8

Speed of a STORM, in km/hr. Precise to .36 km/hr.

STORM	ST N/A	N/A A	7

A three-dimensional region composed of STORM COMPONENTs characterized by reflectivity values above a given threshold, ordered by mass weighted volume.

TIME(Scan)	TS N/A	hr A	6a

The beginning time of a scan, in hours. Precise to 1/3600 hr.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
TIME(Scan) average	TSavg N/A	hr B	6a

The average of all TIMEs(Scan) in the forecast period, in hours. Precise to 1/3600 hr.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
TIME(Scan) current	TScur N/A	hr B	6a

The current scan time, in hours. Precise to 1/3600 hr.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
TRACK VARIANCE(X-direction)	VX N/A	km B	4b

The variance in the STORM position in the X-direction from least squares calculations, in km. Precise to 1/10**4 km.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
TRACK VARIANCE(Y-direction)	VY N/A	km B	4b

The variance in the STORM position in the Y-direction from least squares calculations, in km. Precise to 1/10**4 km.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
X-COEFFICIENT	CVX N/A	km**2 B	10

A coefficient of track variability in the X-direction, in km**2. Precise to 1/10**6 km**2.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
X-POSITION(Centroid)	XC N/A	km A	5a

X-position of a STORM CENTROID (center of mass), in kilometers. Precise to 1/10**4 kilometers.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY	
X-POSITION(Centroid) average	XCavg N/A	km B	5a	Average STORM position in the X-direction from the CORRELATION (Table), in kilometers. Precise to 1/10**4 kilometers.
X-POSITION(Centroid) current	XCcur N/A	km A	5a	Current STORM position in the X-direction, in kilometers. Precise to 1/10**4 kilometers.
X-POSITION(Centroid) forecasted	XCfor N/A	km C	5a	Forecasted STORM CENTROID position in the X-direction, in kilometers. Precise to 1/10**4 kilometers.
X-POSITION(Centroid) previous	XCpre N/A	km A	5a	The previous STORM position in the X-direction, in kilometers. Precise to 1/10**4 kilometers.
X-SPEED(Storm)	XS N/A	km/hr C	8	The speed of a STORM in the X-direction, in km/hr. Precise to .36 km/hr.
X-SPEED(Storm) previous	XSpre N/A	km/hr C	8	The previous speed of a STORM in the X-direction, in km/hr. Precise to .36 km/hr.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY

Y-COEFFICIENT	CVY	km**2	
	N/A	B	10

A coefficient of track variability in the Y-direction, in km**2. Precise to 1/10**6 km**2.

Y-POSITION(Centroid)	YC	km	
	N/A	A	5a

Y-position of a STORM CENTROID (center of mass), in kilometers. Precise to 1/10**4 kilometers.

Y-POSITION(Centroid)	YCavg	km	
average	N/A	A	5a

Average STORM CENTROID position in the Y-direction from the CORRELATION (Table), in kilometers. Precise to 1/10**4 kilometers.

Y-POSITION(Centroid)	YCcur	km	
current	N/A	A	5a

The current STORM CENTROID position in the Y-direction from the CORRELATION (Table), in kilometers. Precise to 1/10**4 kilometers.

Y-POSITION(Centroid)	YCfor	km	
forecasted	N/A	C	5a

Forecasted STORM CENTROID position in the Y-direction from the CORRELATION (Table), in kilometers. Precise to 1/10**4 kilometers.

Y-POSITION(Centroid)	YCpre	km	
previous	N/A	A	5a

The previous STORM CENTROID position in the Y-direction from the CORRELATION (Table), in kilometers. Precise to 1/10**4 kilometers.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
Y-SPEED(Storm)	YS N/A	km/hr C	8

The speed of a STORM in the Y-direction, in km/hr. Precise to .36 km/hr.

Y-SPEED(Storm) previous	YSpre N/A	km/hr B	8

The previous speed of a STORM in the Y-direction, in km/hr. Precise to .36 km/hr.

NEXRAD REVISION DATA ELEMENTS

SORTED BY NAME

ALGORITHM NUMBER 9 - STORM STRUCTURE

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY	
AREA(Storm Component)	A N/A	km**2 A	7	Area of a STORM COMPONENT at a particular ELEVATION, in km**2. Precise to 1/10**6 km**2.
DIRECTION(Storm)	DS N/A	radians A	8	Direction from which a STORM is moving, in radians. Precise to 1/10**3 radians.
ELEVATION	PHI# N/A	radians A	2	Elevation angle, in radians. Precise to 1/10**3 radians.
HEIGHT(Centroid)	HC N/A	km B	5b	The height of a centroid of a STORM COMPONENT above the ground, in kilometers. Precise to 1/10**4 kilometers.
HEIGHT(Storm Component-Centroid)	HSCC N/A	km A	5b	The height of the centroid of a STORM COMPONENT at a particular ELEVATION above the ground, in kilometers. Precise to 1/10**4 kilometers.

NAME	SYMBOL	VALUE	UNITS	CLASS	CATEGORY	
HEIGHT(Storm Component-Centroid) difference	HSCCdif	N/A	km	B	5b	The height difference between centroids of STORM COMPONENTs at two separate ELEVATIONs, in kilometers. Precise to 1/10**4 kilometers.
HEIGHT(Storm Reflectivity) maximum	HSZmax	N/A	km	C	8	The height above the ground where the maximum reflectivity occurs, in kilometers. Precise to 1/10**4 kilometers.
HEIGHT(Storm Spectrum Width) maximum	HWmax	N/A	km	C	8	The altitude where maximum spectrum width occurs, in kilometers. Precise to 1/10**4 kilometers.
INDEX(Elevation)	i	N/A	unitless	B	3	The index for ELEVATION.
MASS(Storm)	MST	N/A	kg	A	10	The mass weighted volume of a STORM, in kilograms. Precise to 1/10**3 kilograms.
OVERHANG ORIENTATION	OVO	N/A	radians	C	8	The overhang orientation between the edge of the STORM COMPONENT at a particular ELEVATION and the centroid of the STORM COMPONENT of the same storm at the lowest ELEVATION, in radians. Precise to 1/10**3 radians.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
PI	PI# 3.1416	unitless A	10

A mathematical constant (3.1416), unitless.

RADIUS CORRECTION(Earth)	RCOE 1.21	unitless A	7

The factor by which the RADIUS(Earth) is multiplied to account for refraction of the radar beam (1.21).

RADIUS(Earth)	RE 6371	km A	7

The radius of the Earth (6371), in kilometers. Precise to 1/10**4 kilometers.

REFLECTIVITY FACTOR(DBZE) maximum	DBZEmax N/A	dBZe A	1

Maximum effective radar reflectivity factor, in dBZe.

REFLECTIVITY(Storm) maximum	ZSmax N/A	dBZe A	1

Maximum effective reflectivity value detected among all STORM COMPONENTs of each STORM, in dBZe.

SPECTRUM WIDTH maximum	Wmax N/A	km/hr A	1

The maximum spectrum width value, in km/hr. Precise to .36 km/hr.

NAME	SYMBOL	VALUE	UNITS	CLASS	CATEGORY	
SPEED(Storm)	SS	N/A	km/hr	A	8	Speed of a STORM, in km/hr. Precise to .36 km/hr.
STORM	ST	N/A	N/A	A,E	7	A three-dimensional region composed of STORM COMPONENTs characterized by reflectivity values above a given threshold, ordered by mass weighted volume.
STORM BASE	STB	N/A	km	C	5a	The altitude of the base of the STORM (lowest STORM COMPONENT), in kilometers. Precise to 1/10**4 kilometers.
STORM OVERHANG	OVH	N/A	km	C	8	The distance between the edge of the STORM COMPONENT at a particular ELEVATION and the centroid of another STORM COMPONENT of the same storm at the lowest ELEVATION, in kilometers. Precise to 1/10**4 kilometers.
STORM SPECTRUM WIDTH maximum	SSWmax	N/A	km/hr	C	1	The maximum spectrum width of a STORM, in km/hr. Precise to .36 km/hr.
STORM TILT	STI	N/A	radians	C	8	The angle (with respect to the Z-axis) between the centroid position of the STORM COMPONENT at the lowest ELEVATION and another STORM COMPONENT within the same storm, in radians. Precise to 1.75 x 1/10**4 radians.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
STORM TOP	STT N/A	km C	5a

The height above the ground of the centroid of the highest STORM COMPONENT, in kilometers. Precise to 1/10**4 kilometers.

STORM VELOCITY(Lowest Elevation) maximum	STEmaxlow N/A	km/hr C	1

The maximum STORM VELOCITY at the lowest ELEVATION, in km/hr. Precise to .6 km/hr.

STORM(X-tilt)	STX N/A	radians C	8

Storm tilt along the X-axis between the centers of mass of STORM COMPONENTs at different ELEVATIONs, in radians. Precise to 1/10**3 radians.

STORM(Y-tilt)	STY N/A	radians C	8

Storm tilt along the Y-axis between the centers of mass of STORM COMPONENTs at different ELEVATIONs, in radians. Precise to 1/10**3 radians.

TIME	T N/A	hr A	6a

The times at which data were collected, in hours. Precise to 1/3600 hr.

VELOCITY(Doppler) maximum	VDmax N/A	km/hr A	1

Maximum Doppler velocity value, in km/hr. Precise to .36 km/hr.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
VOLUME(Storm)	VOL N/A	km**3 C	7

The volume of a STORM, in km**3.

X-POSITION	X N/A	km A	5a

X-position of the CENTROID, in kilometers. Precise to 1/10**4 kilometers.

X-POSITION forecasted	Xfor N/A	km B	5a

The forecasted X-position of the CENTROID, in kilometers. Precise to 1/10**4 kilometers.

X-POSITION highest	Xhgh N/A	km A	5a

X-position of the center of mass of a STORM COMPONENT of the same STORM at the highest ELEVATION, in kilometers. Precise to 1/10**4 kilometers.

X-POSITION lowest	Xlow N/A	km A	5a

X-position of the center of mass of a STORM COMPONENT at the lowest ELEVATION, in kilometers. Precise to 1/10**4 kilometers.

Y-POSITION	Y N/A	km A	5a

Y-position of the CENTROID, in kilometers. Precise to 1/10**4 kilometers.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
Y-POSITION forecasted	Yfor N/A	km B	 5a

The forecasted Y-position of the CENTROID, in kilometers. Precise to 1/10**4 kilometers.

Y-POSITION highest	Yhgh N/A	km A	 5a

Y-position of the center of mass of the STORM COMPONENT of the same STORM at the highest ELEVATION, in kilometers. Precise to 1/10**4 kilometers.

Y-POSITION lowest	Ylow N/A	km A	 5a

Y-position of the center of mass of the STORM COMPONENT at the lowest ELEVATION, in kilometers. Precise to 1/10**4 kilometers.

NEXRAD REVISION DATA ELEMENTS

SORTED BY NAME

ALGORITHM NUMBER 11 - TRANSVERSE WIND

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY	
AZIMUTH	AZ N/A	radians A	2	Azimuthal position, in radians. Precise to 1/10**3 radians.
BOX	BOX N/A	N/A A	7	A window comprised of an equal number of SAMPLE VOLUMES in range and azimuth defining the size of the area to be correlated.
BOX OVERLAP	TBO N/A	percent A	4b	Percent overlap desired from the initial box in the first scan to the next box in the second scan. Overlap values can range from just greater than zero to just under 100%.
BOX(1)	BOX(1) N/A	N/A A	4b	A window comprised of an equal number of SAMPLE VOLUMES in range and azimuth defining the size of the area to be correlated, taken from the first scan.
BOX(2)	BOX(2) N/A	N/A A	4b	A window comprised of an equal number of SAMPLE VOLUMES in range and azimuth defining the size of the area to be correlated, taken from the second scan.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
COEFFICIENT(Correlation Azimuth, #1)	CA1 N/A	unitless B	4a

Coefficient #1 of a second order-equation for the correlation coefficient as a function of azimuth.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
COEFFICIENT(Correlation Azimuth, #2)	CA2 N/A	1/radians B	4a

Coefficient #2 of a second order-equation for the correlation coefficient as a function of azimuth, in 1/radians.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
COEFFICIENT(Correlation Azimuth, #3)	CA3 N/A	1/radians**2 B	4a

Coefficient #3 of a second order-equation for the correlation coefficient as a function of azimuth, in 1/radians**2.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
COEFFICIENT(Correlation Range, #1)	CR1 N/A	unitless B	4a

Coefficient #1 of a second-order equation for the correlation coefficient as a function of range.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
COEFFICIENT(Correlation Range, #2)	CR2 N/A	1/km B	4a

Coefficient #2 of a second-order equation for the correlation coefficient as a function of range, in 1/km.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
COEFFICIENT(Correlation Range, #3)	CR3 N/A	1/km**2 B	4a

Coefficient #3 of a second-order equation for the correlation coefficient as a function of range, in 1/km**2.

NAME	SYMBOL	VALUE	UNITS	CLASS	CATEGORY	
CORRELATION(Coefficient)	CC	N/A	unitless	B	4a	A number representing the degree to which two variables are dependent upon each other.
CORRELATION(Coefficient) optimum	CCopt	N/A	unitless	A	4a	A number representing the optimum degree to which two variables are dependent upon each other.
DIRECTION(Wind)	DW	N/A	radians	C	8	The horizontal direction from which the wind is flowing, in radians. Precise to 1/10**3 radians.
DIRECTION(Wind) average	DWavg	N/A	radians	C	8	The average direction from which the wind is flowing, in radians. Precise to 1/10**3 radians.
ELEVATION	PHI#	N/A	radians	A	2	Elevation angle, in radians. Precise to 1/10**3 radians.
INDEX(Azimuth)	j	N/A	N/A	C	9	The index for AZIMUTH.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
INDEX(Slant Range) The index for RANGE(Slant).	k N/A	N/A A	9
NUMBER OF POINTS(Box) The number of reflectivity points in a BOX.	NOP N/A	unitless C	4a
POSITION(Box) An ordered pair of X and Y coordinates identifying the center of a BOX1, in kilometers.	PB N/A	km C	5a
POSITION(Optimum Correlation Coefficient) An ordered pair of range and azimuth points identifying the position of the optimum correlation coefficient, in kilometers and radians, respectively.	POC N/A	km, radians B	5a
RADIUS(Search) The maximum distance the first BOX can search, in kilometers.	RDS N/A	km B	4a
RANGE(Slant) The slant range to the center of a SAMPLE VOLUME, in kilometers.	RS N/A	km A	2

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY	
REFLECTIVITY FACTOR (DBZE)	DBZE N/A	dBZe A	1	The effective radar reflectivity factor of a SAMPLE VOLUME, in dBZe.
REFLECTIVITY FACTOR (DBZE) first-scan	DBZE(1) N/A	dBZe A	1	First-scan effective radar reflectivity factor of a data SAMPLE VOLUME, in dBZe.
REFLECTIVITY FACTOR (DBZE) second-scan	DBZE(2) N/A	dBZe A	1	Second-scan effective radar reflectivity factor of a data SAMPLE VOLUME, in dBZe.
SECOND-ORDER FIT	SOF N/A	N/A B	4a	Curves fit to range and azimuth data to determine the optimum correlation coefficient location using second-order polynomials.
SECTOR (Transverse Wind)	STW N/A	radians A	7	Reflectivity values from a subset of a radar scan determined by a minimum and maximum range, and minimum and maximum azimuth, in radians.
SPEED(Horizontal Wind)	SHW N/A	km/hr C	8	Horizontal wind speed, in km/hr.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
SPEED(Horizontal Wind)	SHWavg	km/hr	
average	N/A	C	8
The average horizontal wind speed, in km/hr.			
SPEED(Storm)	SS	km/hr	
	N/A	E	8
Speed of a storm, in km/hr.			
TIME	Tcur	hr	
current	N/A	A	6a
The current time at which data is collected, in hours.			
TIME	Tpre	hr	
previous	N/A	A	6a
The previous time at which data was collected, in hours.			
TIME(Scan)	TS	hr	
	N/A	A	6a
The beginning time of a scan, in hours.			
TIME(Scan)	TSdif	hr	
difference	N/A	B	6b
Time difference between scans, in hours.			
VECTOR	VEC	km/hr & radians	
	N/A	C	8
Indicates wind direction and speed. Wind speed is in km/hr and direction is in radians.			

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
VELOCITY(East-West)	VEW N/A	km/hr B	1

The u(east-west) component of the wind speed, in km/hr.

VELOCITY(East-West) average	VEWavg N/A	km/hr C	10

The average east-west component of the horizontal wind in a sector, in km/hr.

VELOCITY(North-South)	VNS N/A	km/hr B	1

The v(north-south) component of the wind speed, in km/hr.

VELOCITY(North-South) average	VNSavg N/A	km/hr C	10

The average north-south component of the horizontal wind in a sector, in km/hr.

X-POSITION optimum	Xopt N/A	km B	5a

X-position of the optimum correlation coefficient value of a BOX, in kilometers.

X-POSITION (Box)	XB N/A	km B	5a

X-position of a BOX(1) center, in kilometers.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
Y-POSITION optimum	Yopt N/A	km B	5a

Y-position of the optimum correlation coefficient value of a BOX, in kilometers.

Y-POSITION (Box)	YB N/A	km B	5a

Y-position of a BOX(1) center, in kilometers.

NEXRAD REVISION DATA ELEMENTS

SORTED BY NAME

ALGORITHM NUMBER 12 - HAIL

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY	
ANGLE(Between Overhang and Direction)	ANG N/A	radians B	5b	The horizontal angle formed by a line from the centroid of the STORM COMPONENT of a STORM at a particular ELEVATION and the centroid of the STORM COMPONENT of the same STORM at the lowest ELEVATION to a line that is parallel to the direction of the storm's movement, in radians.
AREA(Storm Component)	A N/A	km**2 A	8	Area of a STORM COMPONENT at a particular ELEVATION, in km**2.
CONFIDENCE FACTOR	CFA N/A	percent B	4a	The level of confidence in the prediction of hail for a particular storm, in percent.
DEFAULT(Direction)	DDI N/A	radians A	3	A default storm direction value used if directions are not known, in radians.
DEFAULT(Speed)	DSD N/A	km/hr A	3	A default storm speed value used if speeds are not known, in km/hr.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
DIRECTION(Storm) average	DSavg N/A	radians A	8

The average direction from which STORMs are moving, in radians.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
DIRECTION(Storm) nth	DSnth N/A	radians A	8

Direction from which the nth STORM is moving, in radians. Note: If the direction is not determined by the STORM POSITION FORECAST [008] algorithm, then its value is set as being unknown.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
DISTANCE(Between Centroids)	DC N/A	km B	5a

The horizontal distance between the centroid of the STORM COMPONENT of a STORM at the lowest ELEVATION and the centroid of the STORM COMPONENT of the same STORM at some higher ELEVATION, in kilometers.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
DISTANCE(Storm Top and Mid Level)	DTM N/A	km B	5b

The horizontal distance between the centroid of a STORM COMPONENT of a STORM at a midlevel altitude (5 to 12 kilometers) and the centroid of the STORM COMPONENT of the same storm at the highest ELEVATION, in kilometers.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
ELEVATION	PHI# N/A	radians A	2

Elevation angle, in radians.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
HAIL IDENTIFIERS Seven weighted predictors used to determine probability of hail production by a STORM.	HAP N/A	unitless A	10
HEIGHT(Storm Component-Centroid) Height of the centroid of a STORM COMPONENT at a particular ELEVATION above the ground, in kilometers.	HSCC N/A	km B	5a
INDEX(Elevation) The index for ELEVATION.	i N/A	unitless B	8
LABEL A descriptive identifier written for each storm, which identifies the probability of hail production as being positive, potential, probable, a non-hail producer, or that there is insufficient data to analyze the storm.	LAB N/A	N/A C	8
PI A mathematical constant (3.1416), unitless.	PI# 3.1416	unitless B	3
RADIUS CORRECTION (Earth) The factor by which the RADIUS (Earth) is multiplied to account for refraction of the radar beam (1.21).	RCOE 1.21	N/A A	5a

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
RADIUS(Storm Component)	RSC N/A	km B	4a

The radius of a circle whose area is equivalent to the area of the STORM COMPONENT of a particular STORM at a particular ELEVATION, in kilometers.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
RANGE(Slant-Storm Component)	RSSC N/A	km B	5a

Slant range of a centroid at a particular ELEVATION, in kilometers.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
REFLECTIVITY(Storm Component)	ZSC N/A	dBZe A	1

Effective reflectivity value detected in an indivudal STORM COMPONENT, in dBZe.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
REFLECTIVITY(Storm Component) maximum	ZSCmax N/A	dBZe D	8

Maximum effective reflectivity value detected in an individual STORM COMPONENT, in dBZe.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
REFLECTIVITY(Storm) maximum	ZSmax N/A	dBZe D	8

The maximum equivalent reflectivity value detected among all STORM COMPONENTs of each STORM, in dBZe.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
SCORE	SCR N/A	percent C	8

A ratio of the total weight of the positive HAIL IDENTIFIERS to the total possible weight of all successful tests, in percent.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY	
SPEED(Storm)	SS N/A	km/hr A	8	Speed of a STORM, in km/hr. If the speed is not determined by the STORM POSITION FORECAST [008] algorithm, then its value is set as unknown.
SPEED(Storm) average	SSavg N/A	km/hr B	8	The average speed of n STORMs, in km/hr.
STORM	ST N/A	N/A A	7	A three-dimensional region composed of STORM COMPONENTs characterized by reflectivity values above a given threshold, ordered by mass weighted volume.
STORM COMPONENT	STC N/A	N/A A	7	A group of SAMPLE VOLUMEs, contiguous with respect to range (STORM SEGMENTs) and azimuth, at the same elevation angle. More than one may exist at a given elevation.
STORM OVERHANG	OVH N/A	km B	5b	The distance between the edge of the STORM COMPONENT at a particular ELEVATION and the centroid of another STORM COMPONENT of the same storm at the lowest elevation, in kilometers.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
STORM TOP	STT N/A	km A	5a

The height above the ground of the centroid of the highest STORM COMPONENT, in kilometers.

THRESHOLD(Direction Angle)	TDA 1.57	radians A	3

The maximum acceptable deviation of a STORM direction compared to the average direction of all STORMs (1.57), in radians.

THRESHOLD(Hail #1)	TH1 8	km A	3

The minimum STORM TOP height to identify HAIL IDENTIFIER #1 (8), in kilometers.

THRESHOLD(Hail #2)	TH2 55	dBZe A	3

The minimum maximum REFLECTIVITY(Storm) to identify HAIL IDENTIFIER #2 (55), in dBZe.

THRESHOLD(Hail #4)	TH4 .785-3.14	radians A	3

The angle between the overhang and the direction to identify HAIL IDENTIFIER #4 (.785 through 3.14), in radians.

THRESHOLD(Hail #5)	TH5 50	km A	3

The minimum REFLECTIVITY(Storm Component) used to identify HAIL IDENTIFIER #5 (50), in kilometers.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY	
THRESHOLD(Hail #6)	TH6 4	km A	3	The minimum STORM OVERHANG used to identify HAIL IDENTIFIER #6 (4), in kilometers.
THRESHOLD(Hail Height)	THA 5-12	km A	3	The height of a mid-level STORM COMPONENT, used to identify HAIL IDENTIFIERS #3, #4, #5 and #6 (5-12), in kilometers.
THRESHOLD(Hail High Low)	THL 5	km A	3	The maximum height of the centroid of the STORM COMPONENT, used to identify HAIL IDENTIFIERs #2, #3 and #4 (5), in kilometers.
THRESHOLD(Hail Low)	THW 5	km A	3	The maximum height of the lowest elevation STORM COMPONENT, used to identify HAIL IDENTIFIER #3, #4, and #6 (5), in kilometers.
THRESHOLD(High Confidence)	THC 50	N/A A	3	The minimum value to label a STORM as a hail producer (50).
THRESHOLD(High Reflectivity)	TR 70	dBZe A	3	The maximum REFLECTIVITY FACTOR(DBZE) above which the STORM is labelled to be a probable hail producer (70), in dBZe.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
THRESHOLD(High Score)	THI 60	N/A A	3
The minimum score to label a hail producer (60).			
THRESHOLD(Low Confidence)	TLC N/A	N/A A	3
The minimum CONFIDENCE FACTOR to compute a SCORE (25).			
THRESHOLD(Score)	TSC 50	N/A A	3
The maximum value below which a STORM is labelled to be a non-hail producer (50).			
TIME difference	Tdif N/A	hr A	6a
The time difference between the beginning of the volume scan and the current scan time, in hours.			
TIME(Scan)	TS N/A	hr A	6a
The beginning time of a scan, in hours.			
WEIGHT	WGT (HW1-HW7)	unitless A	3
Weight factor (HW1...HW7) associated with each of the HAIL IDENTIFIERS (HW1=17, HW2=7, HW3=15, HW4=8, HW5=20, HW6=15, HW7=18).			

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
WEIGHT(Positive)	WPO N/A	N/A B	4a

Total weight of all the positive HAIL IDENTIFIERS identified. Weight is an integer.

WEIGHT(Probable)	WPR N/A	N/A B	4a

Total weight of all the probable HAIL IDENTIFIERS identified. Weight is an integer.

X-POSITION	X N/A	km A	5a

X-position of the CENTROID, in kilometers.

X-POSITION displacement	Xdis N/A	km B	5b

The displacement between the X-position of the centroid of a STORM COMPONENT at a particular ELEVATION and the location of the centroid of another STORM COMPONENT of the same STORM at the lowest ELEVATION, in kilometers.

X-POSITION highest	Xhgh N/A	km A	5a

The X-position of a centroid of the highest STORM COMPONENT, in kilometers.

X-POSITION lowest	Xlow N/A	km A	5a

The X-position of a centroid of the lowest STORM COMPONENT, in kilometers.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
X-POSITION midlevel	Xmid N/A	km C	5a

The X-position of a centroid of a STORM COMPONENT at a midlevel altitude (5-12 km), in kilometers.

X-SPEED(Storm)	XS N/A	km/hr A	8

The speed of a STORM in the X-direction, in km/hr.

Y-POSITION	Y N/A	km A	5a

Y-position of the CENTROID, in kilometers.

Y-POSITION displacement	Ydis N/A	km B	5b

The displacement between the Y-position of the centroid of a STORM COMPONENT at a particular ELEVATION and the location of the centroid of another STORM COMPONENT of the same STORM at the lowest ELEVATION, in kilometers.

Y-POSITION highest	Yhgh N/A	km A	5a

The Y-position of a centroid of the highest STORM COMPONENT, in kilometers.

Y-POSITION lowest	Ylow N/A	km A	5a

The Y-position of a centroid of the lowest STORM COMPONENT, in kilometers.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
Y-POSITION midlevel	Ymid N/A	km C	5a

The Y-position of a centroid of a STORM COMPONENT at a midlevel altitude (5-12 km), in kilometers.

Y-SPEED(Storm)	YS N/A	km/hr A	8

The speed of a STORM in the Y-direction, in km/hr.

NEXRAD REVISION DATA ELEMENTS

SORTED BY NAME

ALGORITHM NUMBER 13 - ECHO TOPS

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
AZIMUTH	AZ N/A	radians A	2

Azimuthal position, in radians. Precise to 1/10**3 radians.

BOX(4 km X 4 km Grid)	BX4 N/A	N/A D	4b

Square grid boxes which are 4 km on a side and cover ranges from 0 to 230 km.

CATEGORIES	C N/A	unitless A	4b

Categorized effective reflectivity factor data for each SAMPLE VOLUME.

ELEVATION	PHI# N/A	radians A	2

Elevation angle, in radians. Precise to 1/10**3 radians.

HEIGHT(Echo Tops)	HTOP N/A	km B	5a

Height of non-zero values in CATEGORIES for each SAMPLE VOLUME, in kilometers. Precise to 1/10**4 kilometers.

NAME	SYMBOL	UNITS	
	VALUE	CLASS	CATEGORY
RADIUS(Earth)	RE	km	
	6371	A	7

The radius of the Earth (6371), in kilometers. Precise to 1/10**4 kilometers.

RANGE(Slant)	RS	km	
	N/A	A	2

The slant range to the center of a SAMPLE VOLUME, in kilometers. Precise to 1/10**4 kilometers.

TOP(Echo)	TOP	km	
	N/A	C	5a

The greatest height of an echo computed for a BOX(4 km X 4 km Grid), in kilometers. Precise to 1/10**4 kilometers.

NEXRAD REVISION DATA ELEMENTS

SORTED BY NAME

ALGORITHM NUMBER 15 - SEVERE WEATHER PROBABILITY (SWP)

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
BOX(SWP)	BSP	km**2	
	N/A	A	10

An area surrounding a VIL grid box, in km**2.

LIQUID WATER(Integrated)	VIL	kg/km**2	
	N/A	A	8

The integrated liquid water values (per grid box), for a column within a STORM, in kg/km**2.

LIQUID WATER(Integrated-SWP)	VILS	kg/km**2	
	N/A	A	8

The integrated liquid water values in a BOX(SWP), in kg/km**2.

LIQUID WATER(Integrated-SWP)	VILSmax	kg/km**2	
maximum	N/A	A	8

The maximum integrated liquid water value in a BOX (SWP), in kg/km**2.

NO. OF GRID BOXES WITH VIL > 15	FTN	N/A	
	N/A	B	4a

Number of grid boxes with VIL greater than 15.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
NO. OF GRID BOXES WITH VIL > 20	TWY N/A	N/A B	4a

Number of grid boxes with VIL greater than 20.

NO. OF GRID BOXES WITH VIL > 25	TWF N/A	N/A B	4a

Number of grid boxes with VIL greater than 25.

PROBABILITY(Severe Weather)	PWX N/A	percent A	4a

The probability of severe weather, in percent.

SEVERE WEATHER COEFFICIENTS	SW1...SW6 N/A	N/A A	3

The set of coefficients of a regression equation that determines the severe weather propability. The default values are SW1=6.90, SW2=7.39, SW3=0.22, SW4=3.67, SW5=0.01, SW6=2.55.

SWP BOX SIZE	SBS 44 x 44	kilometers A	10

The size of the SWP analysis area, in odd numbered multiples of 4 x 4 kilometer boxes (e.g. 28 x 28, 36 x 36, 44 x 44... etc). The default size is 44 x 44 kilometers.

VIL SIZE	VS N/A	N/A B	8

The number of grid boxes (n) covered by echo, i.e., with integrated liquid water values.

NAME	SYMBOL	UNITS	
	VALUE	CLASS	CATEGORY
VIL WEIGHT	VWT	kg/km**2	
	N/A	B	8

The size of the VIL cell (VS) multiplied by the maximum value of VIL (VILSmax) in the cell, in kg/km**2.

NEXRAD REVISION DATA ELEMENTS

SORTED BY NAME

ALGORITHM NUMBER 16 - MODIFIED VELOCITY VOLUME PROCESSING

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
AZIMUTH	AZ N/A	radians A	 2

Azimuthal position, in radians. Precise to 1/10**3 radians.

DEFORMATION(Horizontal)	DEF N/A	1/hr C	 8

Horizontal deformation of the wind field, in 1/hr.

DERIVATIVE OF u(In X-Direction)	DUX N/A	1/hr C	 8

Derivative of the u-component of wind about the X-axis, in 1/hr.

DERIVATIVE OF u(In Y-Direction)	DUY N/A	1/hr C	 8

Derivative of the u-component of wind about the Y-axis, in 1/hr.

DERIVATIVE OF u(In Z-Direction)	DUZ N/A	1/hr C	 8

Derivative of the u-component of wind about the Z-axis, in 1/hr.

NAME	SYMBOL	UNITS	
	VALUE	CLASS	CATEGORY
DERIVATIVE OF v(In X-Direction)	DVX	1/hr	
	N/A	C	8

Derivative of the v-component of wind about the X-axis, in 1/hr.

DERIVATIVE OF v(In Y-Direction)	DVY	1/hr	
	N/A	C	8

Derivative of the v-component of wind about the Y-axis, in 1/hr.

DERIVATIVE OF v(In Z-Direction)	DVZ	1/hr	
	N/A	C	8

Derivative of the v-component of wind about the Z-axis, in 1/hr.

ELEVATION	PHI#	radians	
	N/A	A	2

Elevation angle, in radians. Precise to 1/10**3 radians.

ELEVATION effective	PHI#eff	radians	
	N/A	A	2

Effective elevation angle, in radians. Precise to 1/10**3 radians.

KINEMATIC PARAMETERS	KP	N/A	
	N/A	B	10

Parameters that are used to estimate atmospheric motions.

NAME	SYMBOL	UNITS	
	VALUE	CLASS	CATEGORY
MATRIX(Predictor)	MXP	N/A	
	N/A	B	10

An m by n matrix of predictor variables where m is the dimension for KINEMATIC PARAMETERS and n is the dimension for the Doppler velocities in a SECTOR.

RADIUS(Earth)	REeff	km	
effective	N/A	A	7

The effective radius of the Earth if the radius appears larger then its true value due to downward bending of the radar beam, in kilometers. Precise to 1/10**4 kilometers.

RANGE(Slant)	RS	km	
	N/A	A	2

The slant range to the center of a SAMPLE VOLUME, in kilometers. Precise to 1/10**4 kilometers.

SECTOR	SEC	radians, km	
	N/A	C	4b

Reflectivity values from a subset of a radar scan in PI/6 radians by 30 kilometer by 2 elevation angle volume, in radians and kilometers. Radians are precise to 1/10**3 radians. Kilometers are precise to 1/10**4 kilometers.

TRANSPOSE	TRN	N/A	
	N/A	B	10

The transpose of a vector or matrix.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
VELOCITY(Doppler)	VD N/A	km/hr A	1

Doppler velocities in a data SAMPLE VOLUME, in km/hr. Precise to .36 km/hr.

VELOCITY(East-West)	VEW N/A	km/hr A	1

The u (east-west) component of the wind speed, in km/hr. Precise to .36 km/hr.

VELOCITY(Modified East-West)	VME N/A	km/hr C	8

The modified component of the east-west wind, in km/hr. Precise to .36 km/hr.

VELOCITY(Modified North-South)	VMN N/A	km/hr C	8

The modified component of the north-south wind, in km/hr. Precise to .36 km/hr.

VELOCITY(North-South)	VNS N/A	km/hr A	1

The v (north-south) component of the wind speed, in km/hr. Precise to .36 km/hr.

X-POSITION(Sector)	XSEC N/A	km B	5a

X-position of the center of a SECTOR limited by range, azimuth and elevation, in kilometers. Precise to 1/10**4 kilometers.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
Y-POSITION(Sector)	YSEC N/A	km B	5a

Y-position of the center of a SECTOR limited by range, azimuth and elevation, in kilometers. Precise to 1/10**4 kilometers.

Z-POSITION(Sector)	ZSEC N/A	km B	5a

Z-position of the center of a SECTOR limited by range, azimuth and elevation, in kilometers. Precise to 1/10**4 kilometers.

NEXRAD REVISION DATA ELEMENTS

SORTED BY NAME

ALGORITHM NUMBER 17 - PRECIPITATION PREPROCESSING

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
AREA(Echo) minimum	AEmin 600	km**2 A	3

The minimum area of precipitation echoes in the low tilt sectors and between the inner and outer RANGEs (Tilt Test) which must be exceeded in order to do the tilt test (600), in km**2.

AREA(Lowest Elevation Echo)	ALE N/A	km**2 B	4a

Echo area including those SAMPLE VOLUMEs with a reflectivity factor greater than the REFLECTIVITY(Tilt Test) from the lowest elevation sectors and between the inner and outer RANGEs(Tilt Test), in km**2.

AREA(Percent Reduction)	APR N/A	Percent E	4a

The percentage echo area from the lowest elevation sectors and between the inner and outer_RANGEs (Tilt Test) which is eliminated by going to the second lowest elevation in percent.

AREA(Percent Reduction) maximum	APRmax N/A	unitless A	3

The percentage of echo area in the lowest elevation sectors and between the inner and outer RANGEs(Tilt Test) which is eliminated by going to the second lowest elevation, which when exceeded, flags lowest elevation scan as being bad (50), in percent.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
AREA(Sample Volume)	ASV N/A	km**2 B	4a

The area of a particular SAMPLE VOLUME in the RATE SCAN to the nearest 0.01 km**2, in km**2.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
AREA(Second Elevation Echo)	ASL N/A	km**2 B	4a

The echo area which satisfies the requirements of AREA (Lowest Elevation Echo) at the lowest elevation but not at the second lowest elevation, in km**2.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
CATEGORY(Precipitation)	CPRE N/A	N/A A	4b

The precipitation category currently in effect.
Category Meaning:
0 = No precipitation detected
during the past hour
1 = Significant precipitation detected
during the past hour
2 = Light precipitation detected
during the past hour

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
ELEVATION	PHI# N/A	radians A	2

Elevation angle, in radians. A precision of at least .001 radians.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
ELEVATION/RANGE/AZIMUTH BOUNDARIES	ERB N/A	radians,km,degrees A	3

The minimum and maximum range and azimuth sector boundaries and ELEVATIONs (4) for which reflectivity factor data are used to build the hybrid scan. The values used will vary from site to site, depending on local terrain, clutter conditions and elevation angles used.

NAME SYMBOL UNITS
VALUE CLASS CATEGORY

FLAG (Zero Hybrid) FHZ N/A
N/A D 10

A set or cleared flag indicating if set, that no precipitation exists in the current scan.

HYBRID SCAN HS dBZe
N/A D 7

Reflectivity factor data on a 1 degree by 1 km polar grid from 1 to 230 km, in dBZe. These data were composited from four elevation scans by the PRECIPITATION PREPROCESSING algorithm. A precision of at least 1 dBZe and dynamic range of at least 0 to 71 dBZe are required.

INDEX(Azimuth) j N/A
N/A B 9

The index for AZIMUTH.

NUMBER(Interpolated Outliers) NIO unitless
N/A E 9

Number of SAMPLE VOLUMEs for which the REFLECTIVITY (Interpolated) was computed.

NUMBER(Isolated SAMPLE VOLUMEs) NIS unitless
N/A E 9

Number of SAMPLE VOLUMEs whose REFLECTIVITY FACTOR (DBZE) is greater than the minimum THRESHOLD(Reflectivity) but are surrounded by less than two SAMPLE VOLUMEs whose REFLECTIVITY FACTOR(DBZE) is greater than the minimum THRESHOLD(Reflectivity).

NAME	SYMBOL	UNITS	
	VALUE	CLASS	CATEGORY

NUMBER(Replaced Outliers)	NRO	unitless	
	N/A	E	9

Number of outliers which have at least one neighbor which is also an outlier and whose REFLECTIVITY FACTOR (DBZE) is replaced with the REFLECTIVITY(Tilt Test).

OCCULTATION CODEs	OC	unitless	
	N/A	A	3

Coded values for each SAMPLE VOLUME which are based on the percentage of the total (two way) beam intensity which is obscured by natural or man-made obstacles under normal propagation conditions.

OCCULTATION(Partial Adjustment)	OCP	dBZe	
	N/A	B	4b

An additive adjustment for beam occultation, in dBZe.

PI	PI#	unitless	
	N/A	B	10

A mathematical constant (3.1416), unitless.

PRECIPITATION STATUS MESSAGE	PSM	N/A	
	N/A	A	4b

An alphanumeric message which includes the radar ID, TIME(Stamp), current radar status, current operational mode, current scan strategy, TIME(Last Precipitation Detected), CATEGORY(Precipitation), number of gages in data base, and time since last update to the gage data base.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
RANGE(Bi-Scan) maximum	RBSmax N/A	km A	 3

Maximum range at which the bi-scan maximization procedure is applied, in kilometers.

RANGE(Slant)	RS N/A	km A	 5a

The slant range to the center of a SAMPLE VOLUME, in kilometers (Precise to 0.1 km).

RANGE(Tilt Test)	RTT 40 and 150 km	km A	 3

The inner and outer range boundaries between which the lowest and second lowest elevation reflectivity data are compared, in kilometers. Will be approximately 40 and 150 km.

RATIO(Bi-Scan)	BIR N/A	unitless E	 4a

The ratio of the number of SAMPLE VOLUMEs used from the second lowest elevation scan to the total number of SAMPLE VOLUMEs used in the Bi-Scan maximization procedure.

REFLECTIVITY FACTOR(DBZE)	DBZE N/A	dBZe A	 1

The effective radar reflectivity factor of a SAMPLE VOLUME, in dBZe. A precision of at least 1 dBZe and a dynamic range of at least 0 to 71 dBZe are required.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
REFLECTIVITY(Area-Averaged) lowest	ZAVlow N/A	dBZe B	4a

The area-averaged reflectivity factor for all SAMPLE VOLUMEs from the lowest elevation sector between the inner and outer RANGEs(Tilt Test) with reflectivity factor greater than or equal to the REFLECTIVITY(Tilt Test), in dBZe. Precise to 0.1 dBZe.

REFLECTIVITY(Area-Averaged) minimum	ZAVmin 10.0	dBZe A	3

The area-averaged reflectivity factor for all SAMPLE VOLUMEs in the lowest elevation sectors between the inner and outer RANGEs(Tilt Test), which must be exceeded in order to perform the tilt test (10.0), in dBZe. A precision of at least 0.1 dBZe is required.

REFLECTIVITY(Complete Occultation)	ZCO N/A	dBZe B	4a

The average of the reflectivity factor values at the same range on either side of the completely occulted SAMPLE VOLUME, in dBZe.

REFLECTIVITY(Interpolated)	ZEI N/A	dBZe B	4a

The average of all eight neighboring SAMPLE VOLUME reflectivities, in dBZe.

REFLECTIVITY(Tilt Test)	ZTT 0-10	dBZe A	3

Low reflectivity, approximately 0 - 10 dBZe.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
SAMPLE VOLUME	SV	N/A	
	N/A	A	7

A data sample volume whose dimensions are 1 degree in azimuth, 1 km in range, and 1 degree in depth (perpendicular to the radar beam).

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
THRESHOLD(Reflectivity-1)	THRmax1	dBZe	
maximum	N/A	A	3

The maximum reflectivity which could be expected when precipitation is occurring, in dBZe.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
THRESHOLD(Reflectivity-1)	THRmin1	dBZe	
minimum	N/A	A	3

The minimum reflectivity factor considered to be nonzero in the test for isolated SAMPLE VOLUMEs, in dBZe.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
TIME(Elevation Scan)	TES	absolute time	
	N/A	A	6a

The time at the beginnning and end of each elevation scan.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
TIME(Elevation Scan)	TESbeg	absolute time	
beginning	N/A	A	6a

Time at which the beginning of a elevation scan was started. A precision of at least 1/1200 hour and an accuracy of 1/120 hour are required.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
TIME(Elevation Scan)	TESend	absolute time	
ending	N/A	A	6a

The time at which the end of a elevation scan occurred. A precision of at least 1/1200 hour and an accuracy of 1/120 hour are required.

NAME SYMBOL UNITS
VALUE CLASS CATEGORY

TIME(Last Precipitation Detected) TLD absolute time
N/A A 6a

The time at which the Precipitation Detection support function last detected precipitation. A precision of at least 1/1200 hour is required.

TIME(Scan) TSavg absolute time
average N/A D 6a

The average scan time of the four elevation scans used to construct the HYBRID SCAN. A precision of at least 1/1200 hours and accuracy to within 1/120 hours are required. This is a time of occurrence, not duration.

TIME(Stamp) TSP absolute time
N/A A 6a

Time at which the Precipitation Detection support function was last executed. A precision at least 1/1200 hour is required.

TIME(Volume Scan) TVO absolute time
N/A A 6a

Time at which a volume scan was completed. A precision of at least 1/1200 hour is required.

NEXRAD REVISION DATA ELEMENTS

SORTED BY NAME

ALGORITHM NUMBER 18 - PRECIPITATION RATE

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
ABSOLUTE DIFFERENCE maximum	ADmax N/A	km**2 B	4b

The maximum ABSOLUTE DIFFERENCE in echo area allowed in order to pass the time continuity test, in km**2.

ABSOLUTE DIFFERENCE(#1)	AD1 N/A	km**2 B	4a

The ABSOLUTE DIFFERENCE between the AREA(Complete Precipitation) and the reference AREA(Inner Precipitation, in km**2.

ABSOLUTE DIFFERENCE(#2)	AD2 N/A	km**2 B	4a

The ABSOLUTE DIFFERENCE between the AREA(Inner Precipitation) and the reference AREA(Complete Precipitation, in km**2.

AREA(Complete Precipitation)	ACP N/A	km**2 B	4a

The precipitation echo area included within a 230 km radius from the radar, in km**2.

AREA(Complete Precipitation) reference	ACPref N/A	km**2 B	4a

The value of AREA(Complete Precipitation) from the previous (good) scan, in km**2.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY	
AREA(Inner Precipitation)	AIP N/A	km**2 B	4a	The precipitation echo area included within the RADIUS (Inner) from the radar, in km**2.
AREA(Inner Precipitation) reference	AIPref N/A	km**2 B	4a	The value of AREA(Inner Precipitation) from the previous (good) scan, in km**2.
AREA(Sample Volume)	ASV N/A	km**2 B	4a	The area of a particular SAMPLE VOLUME in the RATE SCAN to the nearest 0.01 km**2, in km**2.
AREA(Time Continuity) minimum	ATCmin 200	km**2 A	3	Minimum precipitation area to allow time continuity tests on volumetric precipitation rates (200), in km**2.
AZIMUTH	AZ N/A	radians A	5a	Azimuthal position, in radians. Precise to 0.0017 radians.
BOX(1/4 LFM Grid)	BLG N/A	N/A A	10	Rectangular grid box which is 1/4th of the Limited Fine Mesh (LFM) grid used by the National Weather Service. Consists of a file specifying the RATE SCAN data sample volumes whose centers fall within each of the 1/4th LFM grid boxes.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY	
CATEGORY(Precipitation)	CPRE N/A	N/A A	4b	The precipitation category currently in effect. Category Meaning: 0 = No precipitation detected during the past hour 1 = Significant precipitation detected during the past hour 2 = Light precipitation detected during the past hour
COEFFICIENT(Multiplicative Z-R)	CZM 300	N/A A	3	Multiplicative coefficient in the Z-R conversion equation (approximately 300).
COEFFICIENT(Z-R Power)	CZP 1.4	unitless A	3	Power coefficient in the Z-R conversion equation (approximately 1.4).
COEFFICIENTS(Range Effect)	CO1,CO2,CO3 N/A	unitless A	3	Three coefficients used to specify the range effect correction function.
FLAG(Bad)	FB N/A	N/A E	10	When set, designates a precipitation rate scan as including bad data and removes it from further processing.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
FLAG(Zero Hybrid)	FZH N/A	N/A D	10

A set or cleared flag indicating, if set, that no precipitation exists in the current scan.

FLAG(Zero Rate)	FZR N/A	N/A D	10

A set or cleared flag for each average TIME(Scan) indicating, if set, that all precipitation rate values can be assumed to be equal to RATE(Zero Precipitation).

HYBRID SCAN	HS N/A	dBZe D	7

Reflectivity factor data on 1 degree by 1 km polar grid from 1 to 230 km, in dBZe. These data were composited from four elevation scans by the PRECIPITATION PREPROCESSING algorithm. A precision of at least 1dBZe is required.

PARAMETER(Time Continuity #1)	P1 24.0	1/hr A	3

The allowable rate of change of the ratio of volumetric precipitation rates when the echo area is equal to minimum AREA(Time Continuity) (24.0), in 1/hr. Precise to 0.1 1/hr.

PARAMETER(Time Continuity #2)	P2 13.2	1/hr A	3

The allowable rate of change of the ratio of volumetric precipitation rates when the echo area is equal to the full radar umbrella out to the 230 km range (13.2), in 1/hr. Precise to 0.1 1/hr.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
PRECIPITATION STATUS MESSAGE	PSM N/A	N/A A	4b

An alphanumeric message which includes the radar ID, TIME(Stamp), current radar status, current operational mode, current scan strategy, TIME(Last Precipitation Detected), CATEGORY(Precipitation), number of gages in data base, and time since last update to the gage data base.

RADIUS(Inner)	RI	km B	4a

The inner radius to the nearest 1.0 kilometer, in kilometers.

RANGE(Cut-Off)	RCO 150	km A	3

The range beyond which a range effect correction must be applied (150), in kilometers.

RANGE(Slant) midpoint	RSmid N/A	km A	5a

The slant range to the midpoint of a RATE SCAN sample volume in kilometers to the nearest 0.1 km.

RATE SCAN	RSP N/A	dBR D	7

Precipitation rate data on a 1 degree by 2 km polar grid from 1 to 230 km, in dBR. A precision of at least 0.5 dBR and dynamic range of at least -18 to 32 dBR are required (not generated for times when FLAG (Zero Rate) or when FLAG(Bad) are set).

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
RATE(1/4th LFM Grid Box)	RGB N/A	unitless E	7

Area-average rate (8 level coded value) in each 1/4 LFM grid square. A 13 x 13 grid of values for each RATE SCAN used in constructing the hourly accumulations.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
RATE(Complete Reference)	RCR N/A	mm(km**2)/hr B	4a

The RATE(Complete Volumetric Precipitation) for the last good scan, in mm(km**2)/hr.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
RATE(Complete Volumetric Precipitation)	RVP N/A	mm(km**2)/hr B	4a

The total volumetric precipitation rate over the entire field of view out to 230 km, in mm(km**2)/hr.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
RATE(Echo Area Change) maximum	RACmax N/A	km**2/hr A	3

Maximum rate of change of echo area allowed to pass the time continuity test when the volumetric precipitation rate cannot be tested due to the minimum AREA (Time Continuity), in km**2/hr.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
RATE(Inner Reference)	RIR N/A	mm(km**2)/hr B	4a

The RATE(Inner Volumetric Precipitation) for the last good scan, in mm(km**2)/hr.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
RATE(Inner Reference) maximum	RIRmax N/A	mm(km**2)/hr B	4a

The maximum RATE(Inner Reference) for which the current scan can pass the time continuity test, in mm(km**2)/hr.

NAME SYMBOL UNITS
VALUE CLASS CATEGORY

RATE(Inner Volumetric Precipitation) RIV mm(km**2)/hr
N/A B 4a

The total volumetric precipitation rate within the RADIUS(Inner), in mm(km**2)/hr.

RATE(Inner Volumetric Precipitation) RIVmax mm(km**2)/hr
maximum N/A B 4a

The maximum RATE(Inner Volumetric Precipitation) for which the current scan can pass the time continuity test, in mm(km**2)/hr.

RATE(Range Corrected Precipitation) RRC dBR
N/A B 4a

The RATE(Range Corrected Precipitation) with a precision of at least 0.5 dBR and a dynamic range of at least -18 to 32 dBR, in dBR.

RATE(Zero Precipitation) RZP dBR
-17.5 A 3

Precipitation rate assumed to be zero precipitation (-17.5), in dBR. A precision of at least 0.5 dBR is required.

REFLECTIVITY FACTOR (DBZE) DBZE dBZe
N/A A 1

The effective radar reflectivity factor of a SAMPLE VOLUME, in dBZe. A precision of at least 1 dBZe and a dynamic range of at least 0-71 dBZe are required.

SPEED(Storm) SSmax km/hr
maximum 90.0 A 3

The climatologically derived maximum expected storm SPEED to the nearest 1.0 km/hr (90.0), in km/hr.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
THRESHOLD(Max Time Difference)	TMT 0.25	hr A	3

Maximum time between scans (approximately 0.25 hours) allowed by the time continuity test. A precision of at least 0.01 hour is required.

TIME(Scan) average	TSavg N/A	absolute time D	6a

The average scan time of the four elevation scans used to construct the HYBRID SCAN. A precision of at least 1/1200 hours and accuracy to within 1/120 hours are required. This is a time of occurrence, not duration.

TIME(Scan) average difference	TSavgdif N/A	absolute time B	6b

The difference in time at which scans were taken, in hours to the nearest 1/1200 hour.

TIME(Scan) average reference	TSavgref N/A	absolute time B	6a

The reference scan time (of the last good scan) to the nearest 1/1200 hour.

NEXRAD REVISION DATA ELEMENTS

SORTED BY NAME

ALGORITHM NUMBER 19 - PRECIPITATION ACCUMULATION

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
ACCUMULATION SCAN(Hourly)	ASH N/A	dBA D	7

The hourly radar precipitation accumulation data for an hourly running period or clock hour on a 1 degree by 2 kilometer polar grid from 1 to 230 kilometers. A precision of at least 0.5 dBA and a dynamic range of at least -18 to 32 dBA are required. Includes the beginning TIME(Accumulation) and ending TIME(Accumulation).

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
ACCUMULATION SCAN(Period)	ASP N/A	dBA D	7

Interpolated or extrapolated period precipitation accumulation data on a 1 degree by 2 km polar grid from 1 to 230 km, in dBA. A precision of at least 0.5 dBA and a dynamic range of at least -29 to 26 dBA are required.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
ACCUMULATION SCAN(Period) backward-extrapolated	ASPbacext N/A	dBA D	7

The precipitation accumulations for the period from ending TIME(Missing Period) to current average TIME (Scan) obtained by extrapolation from the current RATE SCAN, in dBA. Precise to at least 0.5 dBA.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
ACCUMULATION SCAN(Period) forward-extrapolated	ASPfwdext N/A	dBA D	7

The precipitation accumulations for the period from previous average TIME(Scan) to beginning TIME(Missing Period) obtained by extrapolation from the previous RATE SCAN, in dBA. Precise to at least 0.5 dBA.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
ACCUMULATION SCAN(Period) interpolated	ASPint N/A	dBA D	7

The precipitation accumulations for the period from previous average TIME(Scan) to current average TIME (Scan) obtained by interpolation from the previous and current RATE SCANs, in dBA. Precise to at least 0.5 dBA.

ACCUMULATION SCAN(Scan-to-Scan)	ASS N/A	dBA D	7

The total scan-to-scan accumulation data on a 1 degree by 2 kilometer polar grid from 1 to 230 kilometers. A precision of at least 0.5 dBA and dynamic range of at least -29 to 26 dBA are required. Includes the previous average TIME(Scan) and current average TIME (Scan).

ACCUMULATION(Hourly) interpolated	AHint N/A	dBA B	4a

The interpolated hourly accumulation using the eight neighboring sample volume accumulation values, in dBA. Precise to at least 0.5 dBA.

ACCUMULATION(Rainfall)	ACR N/A	mm B	4a

The rainfall accumulation for a sample volume within a particular ACCUMULATION SCAN(Period), in millimeters. A precision of 0.01 millimeters and a dynamic range of 0 to 398 millimeters are required.

ACCUMULATION(Zero Extrapolated)	AZE N/A	dBA B	4a

The zero level for an extrapolated ACCUMULATION SCAN (Period), in dBA. A precision of at least 0.5 dBA and dynamic range of at least -29 to 26 dBA are required.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
ACCUMULATION(Zero Hourly)	AZH -18	dBA A	3
The hourly precipitation accumulation considered to be zero (-18), in dBA. Precise to 0.5 dBA.			
ACCUMULATION(Zero Interpolated)	AZI N/A	dBA B	4a
The zero level for an interpolated ACCUMULATION SCAN (Period), in dBA. A precision of at least 0.5 dBA and a dynamic range of at least -29 to 26 dBA are required.			
ACCUMULATION(Zero Period)	AZP N/A	dBA B	4a
The zero level for a particular ACCUMULATION SCAN (Period), in dBA. A precision of at least 0.5 dBA and a dynamic range of -29 dBA to 26 dBA are required.			
FLAG(No Hourly Accumulation)	FNA N/A	N/A D	10
A set or cleared flag indicating, if set, that no hourly accumulations were computed for the hour ending at the current ending TIME(Accumulation).			
FLAG(Zero Hourly Accumulation)	FHA N/A	N/A D	10
A set or cleared flag indicating, if set, that all current ACCUMULATION SCAN(Hourly) values can be assumed to be equal to ACCUMULATION(Zero Hourly).			
FLAG(Zero Rate)	FZR N/A	N/A D	10
A set or cleared flag for each average TIME(Scan) indicating, if set, that all precipitation rate values can be assumed to be equal to RATE(Zero Precipitation).			

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
FLAG(Zero Scan-to-Scan)	FZS N/A	N/A D	10

A set or cleared flag indicating, if set, that all current ACCUMULATION SCAN(Scan-to-Scan) values can be assumed to be equal to ACCUMULATION(Zero Interpolated).

NUMBER(Interpolated Accumulation Outliers)	NAO N/A	N/A D	10

The number of hourly accumulation sample volumes that contained hourly outliers which could be removed by interpolation.

PRECIPITATION STATUS MESSAGE	PSM N/A	N/A A	4b

An alphanumeric message which includes the radar ID, TIME(Stamp), current radar status, current operational mode, current scan strategy, TIME(Last Precipitation Detected), CATEGORY(Precipitation), number of gages in data base, and time since last update to the gage data base.

RATE SCAN	RSP N/A	dBR D	7

Precipitation rate data on a 1 degree by 2 km polar grid from 1 to 230 km, in dBR. A precision of at least 0.5 dBR and dynamic range of at least -18 to 32 dBR are required (not generated for times when FLAG(Zero Rate) or when FLAG(Bad) are set).

RATE SCAN current	RSPcur N/A	dBR D	7

The current precipitation rate data on a 1 degree by 2 km polar grid from 1 to 230 km, in dBR. A precision of at least 0.5 dBR and dynamic range of at least -18 to 32 dBR are required.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
RATE SCAN	RSPpre	dBR	
previous	N/A	D	7

The previous precipitation rate data on a 1 degree by 2 km polar grid from 1 to 230 km, in dBR. A precision of at least 0.5 dBR and dynamic range of at least -18 to 32 dBR are required.

THRESHOLD(Hourly Outlier)	THO	dBA	
	26.0	A	3

The maximum hourly rainfall amount allowed in an hourly accumulation scan sample volume (26.0), in dBA. A precision of at least 0.5 dBA is required.

TIME(Accumulation)	TAbeg	absolute time	
beginning	N/A	D	6a

The beginning time of an ACCUMULATION SCAN (Hourly). Precise to 1/1200 hr.

TIME(Accumulation)	TAend	absolute time	
ending	N/A	D	6a

The ending time of an ACCUMULATION SCAN (Hourly). Precise to 1/1200 hr.

TIME(Gage Accumulation)	TGAend	NA	
ending	NA	A	3

The time, each hour, when hourly radar and gage accumulations are required by the PRECIPITATION ADJUSTMENT [020] algorithm. A precision of at least 1/1200 hour is required.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
TIME(Interpolation) maximum	TIPmax 0.5	hr A	3

The maximum period over which a period accumulation scan can be computed using two precipitation rate scans, in hours (approximately 0.5 hours).

TIME(Last Precipitation Detected)	TLD N/A	absolute time A	6a

The time at which the Precipitation Detection support function last detected precipitation. Precise to 1/1200 hr.

TIME(Missing Period)	TMP N/A	absolute time D	6a

The beginning and ending times of any missing periods between the previous scan time and current scan time. Precise to 1/1200 hr.

TIME(Missing Period) beginning	TMPbeg N/A	absolute time D	6a

The beginning times of any missing periods between the previous scan time and current scan time. Precise to 1/1200 hr.

TIME(Missing Period) ending	TMPend N/A	absolute time DC	6a

The ending times of any missing periods between the previous scan time and current scan time. Precise to 1/1200 hr.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
TIME(Period)	TPE N/A	absolute time D	 6a

The beginning and ending times for all ACCUMULATION SCAN(Period) data which are available, in hours. Precise to 1/1200 hr.

TIME(Period) beginning	TPEbeg N/A	absolute time D	 6a

The beginning time for a particular ACCUMULATION SCAN (Period). Precise to 1/1200 hr.

TIME(Period) ending	TPEend N/A	absolute time D	 6a

The ending time for a particular ACCUMULATION SCAN (Period). Precise to 1/1200 hr.

TIME(Period) minimum	TPEmin 0.90	hr A	 3

The minimum period of time during an hourly accumulation period for which ACCUMULATION SCAN(Period) data are required in order to estimate the hourly accumulation, in hours. Precise to 1/60th hr. (approximately 0.90 hours).

TIME(Scan) average	TSavg N/A	absolute time D	 6a

The average scan time of the four elevation scans used to construct the HYBRID SCAN. This is a time of occurrence, not duration.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
TIME(Scan) average current	TSavgcur N/A	absolute time D	6a

The average TIME(Scan) of the current RATE SCAN (or implied zero RATE SCAN if FLAG(Zero Rate) set), to at least 1/1200 hour.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
TIME(Scan) average difference	TSavgdif N/A	absolute time B	6b

The difference in time at which scans were taken, in hours to the nearest 1/1200 hour.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
TIME(Scan) average previous	TSavgpre N/A	absolute time DA	6a

The average TIME(Scan) of the last good RATE SCAN, (or implied zero RATE SCAN if FLAG (zero rate) set), to at least 1/1200 hour.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
WEIGHT FACTOR(Period Accumulation)	WFP N/A	hr B	4a

The time between the beginning of a period and the end of a period which covers a particular ACCUMULATION SCAN (hourly), in hours. Precise to 1/1200 hr.

NEXRAD REVISION DATA ELEMENTS

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ALGORITHM NUMBER 20 - PRECIPITATION ADJUSTMENT

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
ACCUMULATION SCAN(Hourly)	ASH N/A	dBA D	7

The hourly radar precipitation accumulation data for an hourly running period or clock hour on a 1 degree by 2 kilometer polar grid from 1 to 230 kilometers, in dBA. A precision of at least 0.5 dBA and a dynamic range of at least -18 to 32 dBA are required. Includes the beginning TIME(Accumulation) and ending TIME(Accumulation).

ACCUMULATION SCAN(Hourly) adjusted	ASHadj N/A	dBA D	7

Adjusted hourly radar precipitation accumulation data for an hourly running period or clock hour on a 1 degree by 2 kilometer polar grid from 1 to 230 km, in dBA. This data has been adjusted for the mean field bias. A precision of at least 0.5 dBA and dynamic range of at least -18 to 32 dBA are required. Includes the beginning TIME(Accumulation) and ending TIME(Accumulation).

ACCUMULATION SCAN(Scan-to-Scan)	ASS N/A	dBA D	7

The total scan-to-scan accumulation data on a 1 degree by 2 kilometer polar grid from 1 to 230 kilometers for the period from the previous time to the current time, in dBA. A precision of at least 0.5 dBA and a dynamic range of at least -29 to 26 dBA are required. Includes the previous average TIME(Scan) and current average TIME(Scan).

NAME	SYMBOL	VALUE	UNITS	CLASS	CATEGORY	DESCRIPTION
ACCUMULATION SCAN(Scan-to-Scan) adjusted	ASSadj	N/A	dBA	D	7	Total scan-to-scan accumulation data on a 1 degree by 2 km polar grid from 1 to 230 km (in dBA). This data has been adjusted for the estimated mean field bias. A precision of 0.5 at least dBA and dynamic range of at least -29 to 26 dBA are required. Includes the previous average TIME(Scan) and current average TIME(Scan).
ACCUMULATION(Zero Hourly)	AZH	-18	dBA	A	3	The hourly precipitation accumulation considered to be zero, (-18), in dBA. Precise to 0.5 dBA.
ACCUMULATION(Zero Level)	AZL	N/A	dBA	BA	4a	The zero level for the ACCUMULATION SCAN(Scan-to-Scan), in dBA. A precision of at least 0.5 dBA and a range of at least -29 to 26 dBA are required.
BIAS current	Bcur	N/A	unitless	D	4a	The current multiplicative factor that adjusts for the radar bias when compared to surface precipitation measurements.
BIAS forecasted	Bfor	N/A	unitless	D	4a	The forecasted multiplicative factor that adjusts for the radar bias when compared to surface precipitation measurements.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
BIAS previous	Bpre N/A	unitless D	4a

The previous multiplicative factor that adjusts for the radar bias when compared to surface precipitation measurements.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
BIAS reset	Bres 1	unitless A	3

The reset (long term mean) multiplicative factor that adjusts for the radar bias when compared to surface precipitation measurements (presumably 1). A precision of at least 0.01 are required.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
CATEGORY(Precipitation)	CPRE N/A	N/A A	4b

The precipitation category currently in effect.
Category Meaning:
0 = No precipitation detected
during the past hour
1 = Significant precipitation detected
during the past hour
2 = Light precipitation detected
during the past hour

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
DISTANCE MATRIX	DISM N/A	km A	5b

The distance from each gage to every other gage, in kilometers.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
DISTANCE(Between Gages)	DG N/A	km A	5b

The distance between gages in VECTOR (Gage Observation), in kilometers. Precise to 0.1 km.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
DURATION(Incremental Report Overlap)	DIO N/A	hr B	4a

The duration of the portion of a particular incremental gage report that overlaps the hourly accumulation period, in hours to the nearest 1/1200 hour.

FLAG(Missing Data)	FMD N/A	N/A B	10

A flag indicating missing incremental gage report data during the hourly accumulation period.

FLAG(No Hourly Accumulation)	FNA N/A	N/A D	10

A set or cleared flag indicating, if set, that no hourly accumulations were computed for the hour ending at the current ending TIME(Accumulation).

FLAG(Zero Hourly Accumulation)	FHA N/A	N/A D	10

A set or cleared flag indicating, if set, that all current ACCUMULATION SCAN(Hourly) values can be assumed to be equal to ACCUMULATION(Zero Hourly).

FLAG(Zero Scan-To-Scan)	FZS N/A	N/A D	10

A set or cleared flag indicating, if set, that all current ACCUMULATION SCAN(Scan-to-Scan) values can be assumed to be equal to ACCUMULATION(Zero Interpolated).

GAGE ACCUMULATION(Estimated Hourly)	GA N/A	mm B	4a

The estimated hourly accumulation in mm at a gage for the one hour period ending at TAend.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
GAGE ACCUMULATION(Estimated Hourly) accumulator	GAacc N/A	mm B	 4a

The estimated hourly accumulation in mm at a gage for the one hour period ending at TAend computed from accumulator gage reports.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
GAGE ACCUMULATION(Estimated Hourly) incremental	GAinc N/A	mm B	 4a

The estimated hourly accumulation in mm at a gage for the one hour period ending at TAend computed from incremental gage reports.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
GAGE REPORTS(Incremental)	GRI N/A	mm, hr, abs. time A	 10

Reported values of incremental accumulation in mm, increment duration and time of occurrence. Precise to 0.01 mm.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
GAGE REPORTs(Accumulator)	GRA N/A	mm, abs. time A	 10

Reported values of accumulation in mm at each gage and time of occurrence. Precise to 0.01 mm.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
GAGE-RADAR DIFFERENCE	GR N/A	mm B	 4a

The difference in accumulation between a GAGE ACCUMULATION (Estimated Hourly) and the corresponding radar accumulation, in millimeters. Precise to 0.1 mm.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
GAGE-RADAR DIFFERENCE(Normalized)	GRN N/A	unitless B	 4a

The normalized difference in accumulation between an hourly gage report and the corresponding radar accumulation, dimensionless.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
GAGE-RADAR SET	GRS N/A	N/A B	7

The combination of associated pairs of hourly radar accumulations and hourly gage accumulations.

INNOVATIONS	INN N/A	unitless B	4a

A vector of the differences between the VECTOR(Gage Observation) and the VECTOR(Radar Observation) multiplied by the previous BIAS.

INNOVATIONS average	INNavg N/A	mm B	4a

The average of all INNOVATIONS, in mm.

INNOVATIONS(Decay Parameter)	IDP N/A	1/km B	4a

A decay parameter of an isotropic exponential-form covariance function of the difference between the adjusted radar accumulation and the gage accumulation, in 1/km. A precision of at least 4 decimal digits over a range of at least 10**10 to 1/10**10 power is required.

INNOVATIONS(Second Variance Parameter)	ISV N/A	mm**2 B	4a

A second variance parameter which allows for variance at zero distance in addition to the exponential decay portion of an isotropic exponential-form covariance function of the difference between the adjusted radar accumulation and the gage accumulation, in mm**2.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
INNOVATIONS(Variance Parameter)	IV N/A	mm**2 B	4a

A variance parameter of an isotropic exponential-form covariance function of the difference between the adjusted radar accumulation and the gage accumulation, in mm**2.

MATRIX(Covariance Measurement)	MXC N/A	N/A B	4a

A symmetric measurement error covariance matrix.

MATRIX(Gain)	MXG N/A	N/A B	4a

A vector (1 x N matrix) giving the gain values - the multiplicative factors giving the influence of each innovation on the updated bias.

MEAN GAGE RADAR DIFFERENCE	MGR N/A	mm B	4a

The mean of the gage-radar differences in precipitation accumulation, in millimeters. Precise to 0.1 mm.

MEAN SQUARE ERROR current	MSEcur N/A	unitless D	4a

The Mean Square Error (M.S.E.) of the current BIAS value.

MEAN SQUARE ERROR forecasted	MSEfor 0.8	unitless D	4a

The Mean Square Error(M.S.E.) of the forecasted BIAS value.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY	
MEAN SQUARE ERROR maximum	MSEmax 0.8	unitless A	3	The maximum Mean Square Error (M.S.E.) allowed (0.8).
MEAN SQUARE ERROR previous	MSEpre N/A	unitless B	4a	The Mean Square Error (M.S.E.) of the previous BIAS value.
MEAN SQUARE ERROR propagated forecast	MSEprofor N/A	unitless B	4a	The sum of the previous Mean Square Error and SYSTEM NOISE.
MEAN SQUARE ERROR reset	MSEres 0.5	unitless A	3	The reset (long term mean) Mean Square Error (M.S.E.) value used when the M.S.E. has been propagated for an extended time. A precision of at least 0.01 is required.
OBSERVATION(Decay Parameter)	OD N/A	1/km B	4a	A decay parameter of a function that improves the mathematical properties of a matrix composed of the outer product of the VECTOR(Radar Observation), in 1/km. A precision of at least 4 decimal digits over a range of at least 10**10 to 1/10**10 power is required.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
OBSERVATION(Second Variance Parameter)	OSV N/A	mm**2 B	4a

A second variance parameter of the function that improves the mathematical properties of a matrix composed of the outer product of the VECTOR(Radar Observation) in mm**2.

OBSERVATION(Variance Parameter)	OV N/A	mm**2 B	4a

A variance parameter of the function that improves the mathematical properties of a matrix composed of the outer product of the VECTOR(Radar Observation), in mm**2.

PRECIPITATION STATUS MESSAGE	PSM N/A	N/A A	4b

An alphanumeric message which includes the radar ID, TIME(Stamp), current radar status, current operational mode, current scan strategy, TIME(Last Precipitation Detected), CATEGORY(Precipitation), number of gages in data base, and time since last update to the gage data base.

RADAR OBSERVATION	ROB N/A	mm B	8

The radar observation used as part of the gage-radar set by a Kalman filtering procedure. Based on the hourly radar accumulations at the nine sample volumes closest to the gage, in mm.

STANDARD DEVIATION GAGE-RADAR DIFFERENCE	SGR N/A	mm B	4a

The standard deviation of the gage-radar difference in precipitation accumulation, in millimeters. Precise to 0.1 mm.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
SYSTEM NOISE	SYS 0.05	N/A A	3

The estimated mean square error of the drift in the radar BIAS from one hour to the next (0.05).

THRESHOLD(Gage Discard)	TGD 2	unitless A	3

Threshold value of the normalized gage-radar difference to discard the gage data value. A dimensionless number. A precision of at least 0.1 is required.

THRESHOLD(Number of Sets)	TNS 2-10	unitless A	3

The minimum number of GAGE-RADAR SETs for which covariance estimation is allowed (2-10).

THRESHOLD(Time Difference)	TTD N/A	hr A	3

Maximum time (in hours to the nearest 1/60 hour) to the closest GAGE REPORT(Accumulator) for a valid estimate of accumulation at the ending TIME(Gage Accumulation). A precision of at least 1/60 hour is required.

TIME(Accumulation) beginning	TAbeg N/A	absolute time D	6a

The beginning time of an ACCUMULATION SCAN (Hourly). Precise to 1/1200 hr.

TIME(Accumulation) ending	TAend N/A	absolute time D	6a

The ending time of an ACCUMULATION SCAN (Hourly). Precise to 1/1200 hr.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
TIME(Bias Compute) previous	TBCpre N/A	absolute time B	 6a

The time that the BIAS was last computed using gage values.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
TIME(Bias Estimation)	TBE N/A	absolute time A	 3

The time each hour which signals the initiation of the BIAS computation process. A precision of at least 1/60 hour is required.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
TIME(Bias Update) previous	TBUpre N/A	absolute time B	 6a

The time at which the BIAS was last updated, to at least the nearest 1/60 hour.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
TIME(Closest Accumulator) beginning	TZA N/A	absolute time B	 6a

The set of times TGbefbeg, TGaftbeg, TGbefend, TGaftend defining the times of occurrence of GAGE REPORTs (Accumulator) closest in time to TGAbeg and TGAend.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
TIME(Difference #2)	T2 N/A	hr B	 6b

The length of time, in hours to the nearest 1/60 hour, that the BIAS has been propagated forwared without update using gage data.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
TIME(Gage Accumulation) beginning	TGAbeg N/A	absolute time B	 6a

One hour before the ending TIME(Gage Accumulation).

NAME	SYMBOL	VALUE	UNITS	CLASS	CATEGORY	
TIME(Gage Accumulation) ending	TGAend	N/A	hr	A	3	The ending time of the ACCUMULATION SCAN (Hourly) and the computed hourly gage values from which the gage-radar sets are generated. Will be the same time each hour for a particular radar site.
TIME(Gage Interpolation) maximum	TGImax	N/A	hr	A	4a	The maximum time difference in hours from the TIMEs (Gage Report) closest to TAbeg and TAend, respectively.
TIME(Gage Report)	TG	N/A	absolute time	A	6a	The time of a particular accumulator gage report.
TIME(Gage Report) after-beginning	TGaftbeg	N/A	absolute time	B	4a	The TIME(Gage Report) which is after and closest to TGAbeg.
TIME(Gage Report) after-ending	TGaftend	N/A	absolute time	B	4a	The TIME(Gage Report) which is after and closest to TGAend.
TIME(Gage Report) before-beginning	TGbefbeg	N/A	absolute time	B	4a	The TIME(Gage Report) which is before and closest to TGAbeg.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
TIME(Gage Report) before-ending	TGbefend N/A	absolute time B	 4a

The TIME(Gage Report) which is before and closest to TGAend.

TIME(Increment Report Accuracy)	TIA N/A	hr B	 6b

Twice the accuracy of the Begin TIME (Increment Report) or ending TIME (Increment Report), whichever is the least accurate, in hours to the nearest 1/1200 hr.

TIME(Increment Report) beginning	TIbeg N/A	absolute time B	 6a

The time of the start of a particular incremental gage report.

TIME(Increment Report) ending	TIend N/A	absolute time A	 6a

The time of the end of a particular incremental gage report.

TIME(Propagation) maximum	TPRmax 6-48	hr A	 3

Maximum time that the BIAS estimates are allowed to propagate before being reset, in hours. A precision of at least 0.5 hour is required.

TIME(Scan) average current	TSavgcur N/A	absolute time D	 6a

The average TIME(Scan) of the current RATE SCAN (or implied zero RATE SCAN if FLAG (Zero Rate) is set), to at least 1/1200 hour.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
TIME(Scan) average previous	TSavgpre N/A	absolute time D	6a

The averge TIME (Scan) of the last good RATE SCAN (or implied zero RATE SCAN if FLAG (Zero Rate) is set), to at least 1/1200 hr.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
VARIANCE ADJUSTMENT FACTOR	VAF 0.5	unitless A	3

An adjustment factor used to insure that the MATRIX (Measurement Covariance) is positive-definite; a dimensionless number less than 1.0 and greater than or equal to 0 (estimated to be 0.5).

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
VARIANCE INFLATOR	VI N/A	unitless B	4a

A value that reduces the measurement error estimates to account for imperfect prediction of the radar bias itself.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
VECTOR(Gage Observation)	VGO N/A	mm B	4a

The computed hourly gage accumulations for the hour ending with the ending TIME(Gage Accumulation) obtained from the gage reports, in millimeters.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
VECTOR(Radar Observation)	VRO N/A	mm B	8

The hourly radar accumulation for the hour ending at the ending TIME(Gage Accumulation). Each value is based on the hourly accumulation scan values of the sample volume directly over the gage and of the eight surrounding sample volumes, in millimeters.

NEXRAD REVISION DATA ELEMENTS

SORTED BY NAME

ALGORITHM NUMBER 21 - PRECIPITATION PRODUCTS

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
ACCUMULATION SCAN(Hourly)	ASHadj	dBA	
adjusted	N/A	D	7

Adjusted hourly radar precipitation accumulation data for an hourly running period or clock hour on a 1 degree by 2 kilometer polar grid from 1 to 230 km, in dBA. This data has been adjusted for the mean field bias. A precision of at least 0.5 dBA and dynamic range of at least -18 to 32 dBA are required. Includes the beginning TIME(Accumulation) and ending TIME (Accumulation).

ACCUMULATION SCAN(Scan-to-Scan)	ASSadj	dBA	
adjusted	N/A	D	7

Total scan-to-scan accumulation data on a 1 degree by 2 km polar grid from 1 to 230 km, in dBA. This data has been adjusted for the estimated mean field bias. A precision of at least 0.5 dBA and dynamic range of at least -29 to 26 dBA are required. Includes the previous average TIME(Scan) and current average TIME(Scan).

ACCUMULATION(Zero Hourly)	AZH	dBA	
	-18	A	3

The hourly precipitation accumulation considered to be zero (-18), in dBA.

ACCUMULATION(Zero Value)	AZV	mm	
	N/A	B	4a

The zero value for scan-to-scan accumulation data, in, mm. A precision of at least 0.1 mm and a dynamic range from 0 to 1 mm are required.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
ARRAY PRODUCT(Digital Precipitation)	APDP N/A	dBA E	7
The hourly running total or clock hour total on a 1/40th LFM Grid out to 230 km in a > 100 level computer compatible format, including appropriate supplemental data.			
ARRAY TOTAL(Digital Precipitation)	ADP N/A	dBA B	7
Hourly accumulation value for a particular BOX(1/40th LFM Grid), in dBA. A precision of at least 0.5 dBA and dynamic range of at least -18 to 32 dBA is required.			
BOX(1/40 LFM Grid)	BLM N/A	N/A A	10
Rectangular grid box centered on 1/40th LFM grid points. At 60 degrees N the mesh length is 4.7625 km. Specifies the Scan's sample volumes whose centers fall within each grid box. If none, the sample volume whose center is closest to the center of the grid box is specified. Grid boxes whose centers are more than 230 km from the radar are not assigned any sample volumes.			
BOX(2 km X 2 km Grid)	BX N/A	N/A A	10
These are square grid boxes which are 2 km on a side and cover ranges from 0 to 230 km. Specifies the 1 degree by 2 km accumulation scan sample volumes whose centers fall within each grid box. If none, the sample volume whose center is closest to the center of the grid box is specified. Grid boxes whose centers are more than 230 km from the radar are not assigned any sample volumes.			

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
CATEGORY(Precipitation)	CPRE N/A	N/A A	4b

The precipitation category currently in effect.
Category Meaning
0 No precipitation detected during the past hour
1 Significant precipitation detected during the past hour
2 Light precipitation detected during the past hour

FLAG(No Hourly Accumulation)	FNA N/A	N/A D	10

A set or cleared flag indicating, if set, that no hourly accumulations were computed for the hour ending at the current ending TIME(Accumulation).

FLAG(Zero Hourly Accumulation)	FHA N/A	N/A D	10

A set or cleared flag indicating, if set, that all current ACCUMULATION SCAN(Hourly) values can be assumed to be equal to ACCUMULATION(Zero Hourly).

FLAG(Zero Scan-to-Scan)	FZS N/A	N/A D	10

A set or cleared flag indicating, if set, that all current ACCUMULATION SCAN(Scan-to-Scan) values can be assumed to be equal to ACCUMULATION(Zero Interpolated).

IDENTIFIER INFORMATION	ID N/A	N/A E	10

Consists of annotations such as the radar I.D., product name, time (beginning and ending), date and missing period times. The times must be in hours and minutes GMT(Greenwich Mean Time).

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
PRECIPITATION STATUS MESSAGE	PSM N/A	N/A A	4b

An alphanumeric message which includes the radar ID, TIME(Stamp), current radar status, current operational mode, current scan strategy, TIME(Last Precipitation Detected), CATEGORY(Precipitation), number of gages in data base, and time since last update tc the gage data base.

PRECIPITATION TOTAL(Hourly)	PTH N/A	dBA B	4a

The hourly precipitation total for a particular BOX(2 km x 2 km Grid), in dBA. A precision of at least 0.5 dBA and a dynamic range of at least -18 to 32 dBA are required.

PRECIPITATION TOTAL(Scaled Hourly)	PSH N/A	unitless C	4a

The scaled hourly precipitation total for a particular BOX(2 km x 2 km Grid). Scale codes from 0 to 15 will be used in assigning colors in the final display.

PRECIPITATION TOTAL(Scaled Storm)	PSS N/A	unitless C	4a

The scaled precipitation total for a particular BOX(2 km x 2 km Grid). Scale codes 0 to 15 will be used in assigning colors in the final display.

PRECIPITATION TOTAL(Scaled Three Hour)	PTS N/A	unitless C	4a

The scaled three hour precipitation total for a particular BOX(2 km x 2 km Grid). Scale codes from 0 to 15 will be used in assigning colors in the final display.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
PRECIPITATION TOTAL(Storm) current	PSTcur N/A	mm B	4a

The current storm precipitation total for a particular BOX(2 km x 2 km Grid), in mm. A precision of at least 0.1 mm and dynamic range of at least 0 to 1600 mm are required.

PRECIPITATION TOTAL(Storm) partial	PSTpar N/A	mm B	4a

The incremental increase in the precipitation total in mm. A precision of at least 0.1 mm and dynamic range of at least 0 to 398 mm, are required.

PRECIPITATION TOTAL(Storm) previous	PSTpre N/A	mm B	4a

The precipitation total computed previously, in mm. Precise to 0.1 mm.

PRECIPITATION TOTAL(Three Hour)	PT3 N/A	dBA B	4a

The three hour precipitation total for a particular BOX (2 km x 2 km Grid), in dBA. A precision of at least 0.5 dBA and dynamic range of at least -18 to 32 dBA are required.

PRODUCT(Hourly Precipitation)	PHP N/A	N/A C	7

The hourly running total or clock hour total on a 2 km x 2 km grid out to 230 kilometers in a 16 level display-compatible format, including appropriate supplemental data.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
PRODUCT(Storm Total Precipitation)	PSP N/A	N/A C	7

Depicts the total accumulations since the last one hour break in significant precipitation on a 2 km x 2 km grid out to 230 km in a 16 level display-compatible format, including appropriate supplemental data.

PRODUCT(Three Hour Precipitation)	P3H N/A	N/A C	7

The three-hour precipitation accumulation over the past three clock hours on a 2 km x 2 km grid out to 230 km in a 16 level display-compatible format, including appropriate supplemental data.

RATE(1/4TH LFM Grid Box)	RGB N/A	N/A E	4b

Area-averaged rate (8 level coded value) in each 1/4 LFM grid square. A 13 by 13 grid of values for each RATE SCAN used in constructing the hourly accumulations.

SUPPLEMENTAL DATA	SUP N/A	N/A E	4a

A set of data which will be included as annotations to the four precipitation products.

TIME(Last Precipitation Detected)	TLD N/A	absolute time A	6a

The time at which the Precipitation Detection support function last detected precipitation. A precision of at least 1/1200 hour is required.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
TIME(Scan) average current	TSavgcur N/A	absolute time D	 6a

The average TIME(Scan) of the current RATE SCAN to at least 1/1200 hour.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
TIME(Scan) average previous	TSavgpre N/A	absolute time D	 6a

The average TIME(Scan) of the last good RATE SCAN to at least 1/1200 hour.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
TIME(Stamp)	TSP N/A	absolute time A	 6a

Time at which the Precipitation Detection support function was last executed. A precision of at least 1/1200 hour is required.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
TIMES(Three Hour Product Generator)	TPG 0-23	hr A	 3

A list of times for which 2 km x 2 km PRODUCTs(Three Hour Precipitation) should be generated, in hours, up to once per hour (0-23 inclusive).

NEXRAD REVISION DATA ELEMENTS

SORTED BY NAME

ALGORITHM NUMBER 22 - STORM SEGMENTS

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
AZIMUTH	AZ	radians	
	N/A	A,E	1

Azimuthal position, in radians. Precise to 1/10**3 radians.

ELEVATION	PHI#	radians	
	N/A	A,E	1

Elevation angle, in radians. Precise to 1/10**3 radians.

INDEX(Slant Range)	k	N/A	
	N/A	B	9

The index for RANGE (Slant).

MASS MULTIPLICATIVE FACTOR	MMF	(mm**6/m**3)(hr/mm)**PIE	
	486	A	3

A multiplicative factor used in computing the PRECIPITATION INTENSITY (486), (mm**6/m**3)(hr/mm)**PIE.

MASS WEIGHTED FACTOR	MWF	hr(kg)/km**4	
	53 x 10**9	A	3

A factor used in computing the MASS of a (Sample Volume) (53 x 10**9), in hr(kg)/km**4.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY	
MASS WEIGHTED LENGTH	MWL N/A	kg/km**2 C	7	Mass density weighted length of a STORM SEGMENT, in kg/km**2.
MASS WEIGHTED LENGTH SQUARED	MWS N/A	kg/km C	7	Mass density weighted length squared of a STORM SEGMENT, in kg/km.
MASS(Sample Volume)	MSV N/A	kg/km**3 B	8	The mass of liquid water content in a SAMPLE VOLUME, in kg/km**3.
PRECIPITATION INTENSITY	PIN N/A	mm/hr B	4a	Precipitation intensity, in mm/hr (liquid equivalent).
PRECIPITATION INTENSITY EXPONENT	PIE 1.37	N/A A	3	The power to which the PRECIPITATION INTENSITY is raised in calculating the effective REFLECTIVITY FACTOR (DBZE)(1.37).
RANGE(Slant)	RS N/A	km A	2	Slant range to the center of a SAMPLE VOLUME, in kilometers. Precise to 1/10**4 kilometers.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
RANGE(Slant) beginning	RSbeg N/A	km C	2

Beginning slant range to the center of a SAMPLE VOLUME, in kilometers. Precise to 1/10**4 kilometers.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
RANGE(Slant) end	RSend N/A	km C	2

Ending slant range to the center of a SAMPLE VOLUME, in kilometers. Precise to 1/10**4 kilometers.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
REFLECTIVITY AVERAGING FACTOR	ZU 3	unitless A	3

The number of SAMPLE VOLUMES used for determining the average REFLECTIVITY FACTOR(DBZE)(3).

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
REFLECTIVITY FACTOR(DBZE)	DBZE N/A	dBZe A	1

The effective radar reflectivity factor of a SAMPLE VOLUME, in dBZe.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
REFLECTIVITY FACTOR(DBZE) average	DBZEavg N/A	dBZe B	1

The average effective radar reflectivity factor of a group of SAMPLE VOLUMEs, in dBZe.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
REFLECTIVITY FACTOR(DBZE) maximum	DBZEmax N/A	dBZe A	1

The maximum effective radar reflectivity factor, in dBZe.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
REFLECTIVITY FACTOR(ZE)	ZE	mm**6/m**3	
	N/A	B	8

The effective radar reflectivity factor of a SAMPLE VOLUME, in mm**6/m**3.

SAMPLE VOLUME	SV	N/A	
	N/A	A	7

A data sample volume whose dimension are 1 degree in azimuth, 1 km in range, and 1 degree in depth (perpendicular to the radar beam).

SPECTRUM WIDTH	W	km/hr	
	N/A	D	8

Spectrum width value, in km/hr. Precise to .36 km/hr.

SPECTRUM WIDTH	Wmax	km/hr	
maximum	N/A	D	1

The maximum spectrum width value, in km/hr. Precise to .36 km/hr.

STORM SEGMENT	SMT	N/A	
	N/A	C	7

A set of numbered, contiguous SAMPLE VOLUMEs along a radial identified by reflectivity factor values above a specified threshold. A STORM SEGMENT includes: beginning RANGE(Slant), ending RANGE(Slant), maximum REFLECTIVITY FACTOR(DBZE), most minimum and most maximum VELOCITY(Doppler), maximum SPECTRUM WIDTH, AZIMUTH and ELEVATION angle.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
THRESHOLD(Dropout Number)	TDN 2	N/A A	3

The maximum number of SAMPLE VOLUMEs below THRESHOLD (Reflectivity) and above THRESHOLD(Dropout Reflectivity) that may be included in a STORM SEGMENT (2).

THRESHOLD(Dropout Reflectivity)	TDR 25	dBZe A	3

The minimum effective reflectivity of SAMPLE VOLUMEs that are below THRESHOLD(Reflectivity) that may still be included in a STORM SEGMENT (25), in dBZe.

THRESHOLD(Minimum Reflectivity-2)	THR2 30	dBZe A	3

The minimum effective reflectivity in a SAMPLE VOLUME to be included in a STORM SEGMENT (30), in dBZe.

THRESHOLD(Segment Length)	TSL 4.2	km A	3

The minimum length of a STORM SEGMENT (4.2), in kilometers. Precise to 1/10**4 kilometers.

VELOCITY(Doppler)	VD N/A	km/hr A	1

Doppler velocities in a data sample in km/hr. Precise to .36 km/hr.

VELOCITY(Doppler) maximum	VDmax N/A	km/hr D	8

The maximum Doppler velocities, in km/hr. Precise to .36 km/hr.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
VELOCITY(Doppler) minimum	VDmin N/A	km/hr D	8

The minimum Doppler velocities, in km/hr.
Precise to .36 km/hr.

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ALGORITHM NUMBER 23 - TURBULENCE

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY	
ASYMPTOTE(Quasi)	ASY N/A	km**2/3 B	4a	The quasi-asymptotic value, at a range of 220 kilometers, of the curve that estimates the SPECTRUM WIDTH (Normalized Variance), in km**2/3.
BEAM WIDTH	BW .017	radians A	2	The angular width of the radar beam between the half-power points, in radians (.017).
INDEX(Slant Range)	k N/A	unitless A	10	The index for RANGE(Slant).
KOLMOGOROV CONSTANT	KOL 1.35	unitless A	3	A dimensionless constant used to determine turbulence under local isotropic conditions (1.35).
PRECIPITATION FACTOR	PF N/A	unitless A	4a	A dimensionless factor that accounts for imperfect tracers (large drops), when estimating turbulence.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
RANGE(Slant)	RS N/A	km A	2

The slant range to the center of a SAMPLE VOLUME, in kilometers.

REFLECTIVITY FACTOR(DBZE)	DBZE N/A	dBZe A	1

The effective radar reflectivity factor of a SAMPLE VOLUME, in dBZe. Precise to dBZe (Integer value).

SAMPLE VOLUME	SV N/A	N/A A	7

A data sample volume whose dimensions are 1 degree in azimuth, 0.25 km in range, and 1 degree in depth (perpendicular to the radar beam).

SLOPE	SLP N/A	(km**2/3)/km B	4a

The slope, between ranges 0 to 5 km, of the curve that estimates the SPECTRUM WIDTH(Normalized Variance), in km**2/3/km.

SPECTRUM WIDTH(Normalized Variance)	WNV N/A	km**2/3 B	4a

The normalized SPECTRUM WIDTH(Variance), in km**2/3.

SPECTRUM WIDTH(Variance)	WV N/A	km**2/hr**2 A	1

The variance of Doppler spectrum for a data SAMPLE VOLUME, in km**2/hr**2.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
TURBULENCE	TUR N/A	(km**2/3)/hr C	 8

The turbulence that has been corrected for precipitation effects, in (km**2/3)/hr.

TURBULENCE THRESHOLD moderate	TTmod 6.683888	(km**2/3)/hr A	 3

The threshold value indicating the onset of moderate turbulence (6.683888), in (km**2/3)/hr.

TURBULENCE THRESHOLD severe	TTsvr 13.367776	(km**2/3)/hr A	 3

The threshold value indicating the onset of severe turbulence (13.367776), in (km**2/3)/hr.

TURBULENCE(Outer Scale)	TOS 1-4	kilometer A	 4b

The estimated maximum diameter of turbulent eddies for a particular meteorological event (1-4), in kilometers.

TURBULENCE(Uncorrected)	TUU N/A	(km**4/3)/hr**2 A	 8

The turbulence that has not been corrected for precipitation effects, in (km**4/3)/hr**2.

Y-INTERCEPT	YIN N/A	km**2/3 B	 4a

The Y-intercept of the curve that estimates SPECTRUM WIDTH(Normalized Variance), in km**2/3.

NEXRAD REVISION DATA ELEMENTS

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ALGORITHM NUMBER 24 - DIVERGENCE

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  NAME                                          SYMBOL         UNITS
                                                VALUE          CLASS  CATEGORY


  AREA MEASURED(Feature)                         AMF             km**2
                                                 N/A             C      8

            The measured area of the divergence FEATURE (the summa-
            tion of PATTERN VECTOR areas), in km**2.

---------------------------------------------------------------------------

  AREA(Feature)                                  AF              km**2
                                                 N/A             C      8

            The estimated area of the divergence FEATURE, in km**2.

---------------------------------------------------------------------------

  AZIMUTH                                        AZ              radians
                                                 N/A             A      2

            Azimuthal position, in radians.

---------------------------------------------------------------------------

  DIVERGENCE(Radial)                             DVRavg          1/hr
  average                                        N/A             C      8

            The average radial divergence in a divergence FEATURE,
            in 1/hr.

---------------------------------------------------------------------------

  DIVERGENCE(Radial)                             DVRmax          1/hr
  maximum                                        N/A             C      8

            The maximum radial divergence in a divergence FEATURE,
            in 1/hr.

---------------------------------------------------------------------------
```

NAME	SYMBOL	VALUE	UNITS	CLASS	CATEGORY	
ELEVATION	PHI#	N/A	radians	A	2	Elevation angle, in radians. Precise to 1/10**3 radians.
FEATURE	FEA	N/A	N/A	A	10	A set of PATTERN VECTORs which have passed spatial proximity.
FEATURE CENTER POSITION	FCP	N/A	N/A	C	5a	FEATURE center position in range, elevation and azimuth.
FLUX	F	N/A	km**2/hr	B	8	The air mass flux (per unit mass) associated with divergence, in km**2/hr.
FLUX average	Favg -	N/A	km**2/hr	C	8	The average air mass flux (per unit mass) associated with divergence, in km**2/hr.
FLUX maximum	Fmax	N/A	km**2/hr	C	8	The maximum air mass flux (per unit mass) associated with divergence, in km**2/hr.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
HEIGHT(Divergence Feature Center)	HDFC N/A	km B	5a
The height of the divergence FEATURE center, in kilometers. Precise to 1/10**3 km.			
PATTERN VECTOR	PVE N/A	N/A A	10
A vector which is formed when a run of increasing Doppler velocity ends. A PATTERN VECTOR contains five components: the slant range, the azimuth angles at both ends of the run, and the Doppler velocities that correspond to those azimuth angles at the slant range.			
RADIUS(Earth)	RE 6371	km A	7
The radius of the Earth (6371), in kilometers. Precise to 1/10**4 km.			
RANGE(Slant Pattern Vector)	RSPV N/A	km A	10
The slant range of a PATTERN VECTOR, in kilometers. Precise to 1/10**3 km.			
RANGE(Slant Pattern Vector) beginning	RSPVbeg N/A	km B	5a
The beginning slant range of a PATTERN VECTOR, in kilometers. Precise to 1/10**3 km.			
RANGE(Slant Pattern Vector) ending	RSPVend N/A	km B	5a
The ending slant range of a PATTERN VECTOR, in kilometers. Precise to 1/10**3 km.			

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
RANGE(Slant)	RS N/A	km A	1

The slant range to the center of a SAMPLE VOLUME, in kilometers.

RANGE(Slant) average	RSavg N/A	km A	5a

The average slant range of a divergence FEATURE, in kilometers. Precise to 1/10**3 km.

REFLECTIVITY FACTOR(DBZE)	DBZE N/A	dBZe A	1

The effective radar reflectivity factor of a SAMPLE VOLUME, in DBZe.

SHEAR(Radial)	S N/A	1/hr B	8

The change in Doppler velocity along a radial, in 1/hr.

THRESHOLD(Azimuth)	TAZ 0.035	radians A	1

The maximum azimuthal separation between PATTERN VECTORs (0.035), in radians.

THRESHOLD(Divergence Range)	TDI 3.5	kilometers A	4b

A value that represents the maximum range separation between PATTERN VECTOR centers (3.5), in kilometers.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
THRESHOLD(Divergence-High Shear)	TDHS 7.2	1/hr A	4b
A value which represents the minimum magnitude of shear expected in divergence in the presence of minimal air mass flux (7.2), in 1/hr.			
THRESHOLD(Divergence-Low Shear)	TDLS 3.6	1/hr A	4b
A value which represents the minimum magnitude of shear expected in divergence (3.6), in 1/hr.			
THRESHOLD(Height)	THH 8	kilometers A	4b
Only pattern vectors above this threshold will be checked for divergence (8), in kilometers.			
THRESHOLD(High Flux)	THF 108	1/hr A	4b
A value which represents the minimum magnitude of air mass flux expected in divergence in the presence of minimal shear (108), in 1/hr.			
THRESHOLD(Low Flux)	TLF 36	1/hr A	4b
A value which represents the minimum magnitude of air mass flux expected in divergence (36), in 1/hr.			
THRESHOLD(Pattern Vector Number)	TPN 6	unitless A	4b
The minimum number of PATTERN VECTORs within a FEATURE (6).			

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY	
THRESHOLD(Velocity Reflectivity)	TVR 15	dBZe A	4b	The REFLECTIVITY FACTOR(DBZE) above which Doppler velocities will be processed (15), in dBZe.
VELOCITY(Doppler)	VD N/A	km/hr A	1	Doppler velocities in a data sample volume, in km/hr.
VELOCITY(Doppler) average-difference	VDavgdif N/A	km/hr A	1	The average Doppler velocity difference in a divergence FEATURE, in km/hr.
VELOCITY(Doppler) beginning	VDbeg N/A	km/hr B	1	The Doppler velocity at the beginning of a PATTERN VECTOR, in km/hr.
VELOCITY(Doppler) ending	VDend N/A	km/hr B	1	The Doppler velocity at the end of a PATTERN VECTOR, in km/hr.
VELOCITY(Doppler) maximum-difference	VDmaxdif N/A	km/hr A	1	The maximum Doppler velocity difference in a divergence FEATURE, in km/hr.

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ALGORITHM NUMBER 26 - TVS DETECTION

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY	
AZIMUTH	AZ N/A	radians A	2	Azimuthal position, in radians. Precise to 1/10**3 radians.
AZIMUTH beginning-feature	AZbegfe N/A	radians A	2	The beginning azimuth of a FEATURE, in radians. Precise to 1/10**3 radians.
AZIMUTH ending-feature	AZendfe N/A	radians A	2	The ending azimuth of a FEATURE, in radians. Precise to 1/10**3 radians.
AZIMUTH feature	AZfe N/A	radians A	2	The azimuthal positions of a FEATURE, in radians. Precise to 1/10**3 radians.
AZIMUTH(Maximum Velocity)	AMV N/A	radians B	4a	The azimuth of a maximum VELOCITY(Doppler Range) within a FEATURE, in radians. Precise to 1/10**3 radians.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
AZIMUTH(Minimum Velocity)	ANV N/A	radians B	4a

The azimuth of a minimum VELOCITY(Doppler Range) within a FEATURE, in radians. Precise to 1/10**3 radians.

ELEVATION	PHI# N/A	radians A	2

Elevation angle, in radians. Precise to 1/10**3 radians.

FEATURE	FEA N/A	N/A A	10

A set of PATTERN VECTORs which have passed spatial proximity.

FEATURE EXTREMA	FEX N/A	N/A A	4a

A set of four parameters (beginning RANGE(Slant-Feature), ending RANGE(Slant-Feature), beginning Feature AZIMUTH and ending Feature AZIMUTH). These are the maximum and minimum AZIMUTHS of its PATTERN VECTOR LIST, and the maximum and minimum ranges from the PATTERN VECTOR LIST.

HEIGHT(TVS Feature)	HTVS N/A	km B	5a

The height above the ground of a TVS FEATURE, in kilometers. Precise to 1/10**4 kilometers.

INDEX(Slant Range)	k N/A	N/A B	7

The index for RANGE(Slant).

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
MESOCYCLONE ID	MESID N/A	N/A A	7

An ID assigned to a mesocyclone when the mesocyclone algorithm identifies a mesocyclone.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
ORIENTATION	ORI N/A	radians C	4a

The orientation of the maximum and minimum Doppler velocity locations within a FEATURE at the same elevation, in radians. Precise to 1/10**3 radians.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
RADIUS CORRECTION(Earth)	RCOE 1.21	unitless A	7

The factor by which the RADIUS(Earth) is multiplied to account for refraction of the radar beam (1.21).

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
RADIUS(Earth)	RE 6371	km A	7

The radius of the Earth (6371), in kilometers. Precise to 1/10**4 kilometers.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
RANGE(Maximum Velocity)	RMV N/A	km B	5a

The slant range of maximum VELOCITY(Doppler Range) within a FEATURE, in kilometers. Precise to 1/10**4 kilometers.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
RANGE(Maximum)	RSM N/A	km B	5a

The slant range of maximum VELOCITY(Doppler Range), in kilometers. Precise to 1/10**4 kilometers.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
RANGE(Minimum Velocity)	RNV N/A	km B	5a

The slant range of minimum VELOCITY(Doppler Range) within a FEATURE, in kilometers. Precise to 1/10**4 kilometers.

RANGE(Minimum)	RSN N/A	km B	5a

The slant range of minimum VELOCITY(Doppler Range), in kilometers. Precise to 1/10**4 kilometers.

RANGE(Slant)	RS N/A	km A	2

The slant range to the center of a SAMPLE VOLUME, in kilometers. Precise to 1/10**4 kilometers.

RANGE(Slant-Feature)	RSFE N/A	km A	5a

The slant ranges of a FEATURE, in kilometers. Precise to 1/10**4 kilometers.

RANGE(Slant-Feature) beginning	RSFEbeg N/A	km A	5a

The beginning slant range of a FEATURE, in kilometers. Precise to 1/10**4 kilometers.

RANGE(Slant-Feature) ending	RSFEend N/A	km A	5a

The ending slant range of a FEATURE, in kilometers. Precise to 1/10**4 kilometers.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
ROTATION	ROT N/A	radians C	4a

The rotation of the velocity field within a FEATURE at the same elevation, in radians. Precise to 1/10**3 radians.

SEARCH BOUNDARY(Azimuth) beginning	SBAbeg N/A	radians B	4a

The beginning azimuth of a FEATURE adjusted for the SEARCH PERCENTAGE, in radians. Precise to 1/10**3 radians.

SEARCH BOUNDARY(Azimuth) ending	SBAend N/A	radians B	4a

The ending azimuth of a FEATURE adjusted for the SEARCH PERCENTAGE, in radians. Precise to 1/10**3 radians.

SEARCH BOUNDARY(Slant Range) beginning	SBRbeg N/A	km B	4a

The beginning slant range of a FEATURE adjusted for the SEARCH PERCENTAGE, in kilometers. Precise to 1/10**4 kilometers.

SEARCH BOUNDARY(Slant Range) ending	SBRend N/A	km B	4a

The ending slant range of a FEATURE adjusted for SEARCH PERCENTAGE, in kilometers. Precise to 1/10**4 radians.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
SEARCH PERCENTAGE	PCT .05	unitless A	3

The percent areal increase for searching for TVSs (.05), unitless. (.05 is equivalent to 5 percent).

SHEAR POSITION	SHP N/A	km & radians C	10

The position in range and azimuth of the maximum SHEAR (TVS) position.

SHEAR POSITION(Azimuth)	SRA N/A	radians C	5a

The azimuth of the SHEAR POSITION, in radians. Precise to 1/10**3 radians.

SHEAR POSITION(Range)	SRR N/A	km C	5a

The slant range of the SHEAR POSITION, in kilometers. Precise to 1/10**4 kilometers.

SHEAR(TVS)	STV N/A	1/hr C	4a

The change between the maximum and minimum Doppler velocities within a FEATURE at the same elevation, in 1/hr. Precise to 1/3600 hr.

SHEAR(TVS) maximum	STVmax N/A	1/hr C	4a

The maximum change between the maximum and minimum Doppler velocities within a FEATURE at the same elevation, in 1/hr. Precise to 1/3600 hr.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
THRESHOLD(TVS Shear)	TTV	1/hr	
	180	A	3

The minimum SHEAR(TVS) expected within a TVS FEATURE (180), in 1/hr. Precise to 1/3600 hr.

TVS FEATURE POSITION	TVS	km & radians	
	N/A	C	5a

The position of a TVS FEATURE in range, azimuth and height.

VELOCITY(Doppler Range)	VDRmax	km/hr	
maximum	N/A	B	4a

The maximum Doppler velocity along each radial, in km/hr. Precise to .36 km/hr.

VELOCITY(Doppler Range)	VDRmin	km/hr	
minimum	N/A	B	4a

The minimum Doppler velocity along each radial, in km/hr. Precise to .36 km/hr.

VELOCITY(Doppler)	VD	km/hr	
	N/A	A	1

The Doppler velocities in a data sample volume, in km/hr. Precise to .36 km/hr.

VELOCITY(Doppler)	VDmax	km/hr	
maximum	N/A	B	4a

The maximum Doppler velocities, in km/hr. Precise to .36 km/hr.

NAME	SYMBOL	UNITS	
	VALUE	CLASS	CATEGORY
VELOCITY(Doppler)	VDmin	km/hr	
minimum	N/A	B	4a

The minimum Doppler velocities, in km/hr. Precise to .36 km/hr.

NEXRAD REVISION DATA ELEMENTS

SORTED BY NAME

ALGORITHM NUMBER 27 - SECTORIZED UNIFORM WIND

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
AZIMUTH	AZ N/A	radians A	1

Azimuthal position, in radians. Precise to 1.75 x 1/10**3 radians.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
AZIMUTH begin interpolation	AZbegi N/A	radians B	4a,5a

The AZIMUTH at which VELOCITY (Begin Interpolation) is located, in radians.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
AZIMUTH end interpolation	AZendi N/A	radians B	4a,5a

The AZIMUTH at which VELOCITY(End Interpolation) is located, in radians.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
AZIMUTH(Filtered Velocities)	AFL N/A	radians A	3

A set of AZIMUTHS for which VELOCITY FILTERED will be calculated. This is currently specified as groups of 3 adjacent AZIMUTHS centered every 10 degrees around an AZIMUTH sweep, beginning at 0 degrees, in radians. Precise to 1.75 x 1/10**3 radians.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
AZIMUTH(Filtered Velocity) after	AFLaft N/A	radians B	4a,5a

The AZIMUTH of the radial after AZIMUTH (Filtered Velocity), in radians.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY	
AZIMUTH(Filtered Velocity) before	AFLbef N/A	radians B	4a,5a	The AZIMUTH of the radial before AZIMUTH (Filtered Velocity), in radians.
DATA(Bad)	DTB N/A	unitless A	3	A value which indicates missing or poor quality data assigned to velocity data to prevent processing by the algorithm.
DERIVATIVE(Azimuthal)	DAZ N/A	(km/hr)(1/radians) B	4a	The azimuthal derivative of the Doppler estimated radial velocity (transverse component), in (km/hr) (1/radians).
ELEVATION	PHI# N/A	radians A	1	Elevation angle, in radians. Precise to 1.75 x 1/10**3 radians.
FREQUENCY(Cutoff)	FCO .015	unitless A	3	The cutoff frequency of the filter (.015 cycles per data interval recommended by the author).
GAP	GAP N/A	radians B	4a,5a	The azimuthal width in radians separating two VELOCITYs (Range Interval Averaged), between which there is missing or bad data. Precise to 1.75 x 1/10**3 radians.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
GAP maximum	GAPmax N/A	radians A	3

The maximum number of radians over which a gap can exist in velocity data around an AZIMUTH sweep at one range and still have linear interpolation performed across it to estimate the missing velocity values. Precise to 1.75 x 1/10**3 radians.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
INTERVAL(Average)	INA 6.75	km A	3

An interval, in kilometers, over which velocity data are to be averaged over a radial, i.e., the length of a RANGE INTERVAL (6.75 is currently used in NSSL implemented). Precise to 1/10**4 km.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
INTERVAL(Class)	INC N/A	m/s B	4a

One of a set of intervals into which VELOCITYs(Doppler) are divided in order to determine first, the modal (or most frequent value), and then the average value of the VELOCITY(Doppler) over a RANGE INTERVAL. Each INTERVAL(Class) has a width of INTERVAL(Width). Precise to .1 m/s.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
INTERVAL(Mode)	INTM N/A	unitless B	4a

The INTERVAL(Class) which contains the most frequently occurring velocity values over a RANGE INTERVAL.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
INTERVAL(Width)	INW N/A	km/hr A	3

The width of a class interval for determining an average velocity in a RANGE INTERVAL (7.2 km/hr is currently used in NSSL implementation). Precise to .36 km/hr.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY	
NUMBER	N N/A	unitless A	3	The number of unique Lanczos filter weights to use in actual computation.
NUMBER(Missing Velocity)	NMV N/A	unitless B	9	Number of the missing velocity in the gap for which an interpolated value is desired.
NUMBER(Weights)	NWT 51	unitless A	3	The number of unique Lanczos filter weights used to obtain the desired filtering characteristics. It must be an odd number with 51 currently being used in the NSSL implementation.
PI	PI# N/A	unitless B	10	A mathematical constant (3.1416), unitless.
RANGE INTERVAL	RNT N/A	km A	3	The interval over which to average the velocities over a radial before the wind field is computed, in kilometers (6.75 is currently used in NSSL implementation). Precise to 1/10**4 km.
RANGE(Center Interval)	RCI N/A	m B	4a	The RANGE at the center of a RANGE INTERVAL, i.e., the RANGE (Slant) corresponding to a VELOCITY (Filtered) or a VELOCITY (Range Interval Averaged). Precise to .1m.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY	
RANGE(Slant)	RS N/A	km A	1	The slant range to the center of a SAMPLE VOLUME, in kilometers. Precise to 1/10**4 km.
VELOCITY (Range Interval Averaged)	VRA N/A	km/hr B	4a	The average velocity over a RANGE INTERVAL, in km/hr.
VELOCITY FILTERED	VFL N/A	km/hr B	4a	A VELOCITY(Range Interval Averaged) which has been filtered by the low pass Lanczos filter, in km/hr.
VELOCITY FILTERED after	VFLaft N/A	unitless B	4a	The VELOCITY FILTERED immediately after VELOCITY (Azimuthal Derivative) as AZIMUTH is incremented.
VELOCITY FILTERED before	VFLbef N/A	unitless B	4a	The VELOCITY FILTERED immediately before VELOCITY (Azimuthal Derivative).
VELOCITY(Azimuthal Derivative)	VA N/A	unitless B	4a	The filtered velocity about which a centered difference approximation of Azimuthal Derivative is to be computed.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
VELOCITY(Begin Interpolation)	VBI N/A	unitless B	4a,5a
A valid VELOCITY (Range Interval Averaged) (i.e., not equal to DATA (Bad)) encountered at a RANGE (Center Interval) after which missing velocity values are encountered as AZIMUTH is incremented.			
VELOCITY(Doppler)	VD N/A	km/hr A	1
Doppler velocities in a data SAMPLE VOLUME, in km/hr. Precise to .1m/s.			
VELOCITY(End Interpolation)	VEI N/A	unitless B	4a
A valid VELOCITY (Range Interval) at a RANGE(Center Interval) which is encountered just after a missing velocity value as AZIMUTH is incremented.			
VELOCITY(Interpolated)	VIN N/A	unitless B	4a
A VELOCITY which is estimated from VELOCITYs (Range Interval Average), and is thereafter considered to be part of that set of velocities.			
VELOCITY(Interval Center)	VELINC N/A	km/hr B	4a
The VELOCITY(Doppler) at the center of an INTERVAL (Class), in km/hr.			
VELOCITY(Maximum Class Interval)	VELMX N/A	hr B	4a
The largest (or ending) VELOCITY(Doppler) in an INTERVAL(Class), in km/hr.			

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
VELOCITY(Minimum Class Interval)	VELMN N/A	km/hr B	4a

The mimimum (or beginning) VELOCITY(Doppler) in an INTERVAL(Class), in km/hr.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
VELOCITY(Minimum Number)	VNM N/A	unitless A	3

The minimum number of velocities which must be in the INTERVAL(Mode) before an average velocity is computed.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
VELOCITY(Number in Interval)	VNUM N/A	unitless B	4a

The number of VELOCITYs (Doppler) which fall into each INTERVAL (Class) over a RANGE INTERVAL. There is one value of VELOCITY (Number in Interval) for each INTERVAL(Class).

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
WEIGHT(Lanczos Filter)	WTLF N/A	unitless B	4a

The filtering weights which are determined according to the Lanczos filtering scheme.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
WEIGHT(Normalized)	WNOR N/A	unitless B	4a

A member of the set of Lanczos filter weights normalized by WEIGHT(Sum).

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
WEIGHT(Sum)	WTS N/A	unitless B	4a

The sum of the Lanczos Filter weights.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
WIND (Meteorological Direction)	WME N/A	degrees E	4a

The wind direction, in degrees, according to meteorological convention.

WIND SPEED	WSP N/A	m/s E	4a

The velocity estimate from the SECTORIZED UNIFORM WIND (027) algorithm, valid over a sector consisting of one set of AZIMUTHS (Filtered Velocities) and a RANGE INTERVAL. Precise to .1m/s.

WIND(Direction)	WDR N/A	degrees E	4a

The wind direction estimated from the SECTORIZED UNIFORM WIND (027) algorithm, valid over a volume of space defined by one set of AZIMUTHS (Filtered Velocities) and a RANGE INTERVAL. Precise to 1/10**3 radians.

NEXRAD REVISION DATA ELEMENTS

SORTED BY NAME

ALGORITHM NUMBER 29 - GUST FRONT DETECTION

NAME	SYMBOL	VALUE	UNITS	CLASS	CATEGORY	
AREA	AFE	N/A	km**2	B	10	The area of a FEATURE, in km**2.
AZIMUTH	AZ	N/A	radians	A	10	Azimuthal position, in radians.
AZIMUTH POSITION	AZPO	N/A	azimuth	C	10	The position of a point in a FEATURE, in azimuth.
ELEVATION	PHI#	N/A	radians	A	10	Elevation angle, in radians.
FEATURE CENTER(Azimuth)	FCAZ	N/A	azimuth	E	10	The FEATURE center position, in azimuth.
FEATURE CENTER(Slant Range)	FCRS	N/A	range	E	10	The FEATURE center position, in range.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
FEATURE FLUX maximum	FFmax N/A	km**2/hr E	10
The maximum FLUX of a FEATURE, in km**2/hr.			
FEATURE(Convergence)	FEAC N/A	N/A E	10
A set of PATTERN VECTORs(Radial) in close spatial proximity.			
FLUX(Convergence)	FVVC N/A	km**2/hr A	10
The flux of a PATTERN VECTOR(Radial), in km**2/hr.			
GRADIENT	G N/A	1/hr E	10
The gradient of a PATTERN VECTOR (Radial), in 1/hr.			
GRADIENT average of the maximum	Gavgmax N/A	1/hr E	10
The average of the maximum gradients of the PATTERN VECTORs(Radial) which comprise a FEATURE, in 1/hr.			
GRADIENT maximum	Gmax N/A	1/hr E	10
The maximum gradient of a 5 point section of a PATTERN VECTOR(Radial), in 1/hr.			

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
LENGTH(Azimuthal)	LAZ N/A	km C	10

The length along an azimuth of a FEATURE, in km.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
MAXIMIN	MAXIMIN N/A	unitless C	10

The highest of seven adjacent Doppler velocities, which is less than or equal to the current velocity.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
MAXIMUM DISTANCE FEATURE(Convergence)	MFDI 5	km A	3

A value that represents the maximum horizontal distance that a FEATURE(Convergence) center can travel between two volume scans (5.0), in kilometers.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
NUMBER of PATTERN VECTORs(Radial)	NVV N/A	unitless A	10

The actual number of PATTERN VECTORs(Radial) comprising a possible FEATURE.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
PATTERN VECTOR(Radial)	PVER N/A	unitless E	10

The vector which is formed when a run of decreasing Doppler velocity ends. A PATTERN VECTOR (Radial) contains six components: the beginning and ending Doppler velocity, beginning and ending range, azimuth, and maximum gradient.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
PI	PI# 3.1416	unitless C	10

A mathematical constant (3.1416), unitless.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
RADIAL CONVERGENCE	RC N/A	1/hr B	4a

The radial convergence in a FEATURE, in 1/hr.

RADIAL CONVERGENCE average	RCavg N/A	1/hr E	10

The average radial convergence in a FEATURE, in 1/hr.

RADIAL CONVERGENCE maximum	RCmax N/A	1/hr A	10

The maximum radial convergence in a FEATURE, in 1/hr.

RANGE(Slant-Gust Front)	RSVV N/A	km E	10

The slant ranges of a PATTERN VECTOR(Radial), in kilometers.

RANGE(Slant-Gust Front) beginning	RSVVbeg N/A	km E	10

The beginning slant range of a PATTERN VECTOR(Radial), in kilometers.

RANGE(Slant-Gust Front) ending	RSVVend N/A	km E	10

The ending slant range of a PATTERN VECTOR(Radial), in kilometers.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
REFLECTIVITY FACTOR(DBZE)	DBZE N/A	dBZe A	10

The effective radar reflectivity factor of a SAMPLE VOLUME, in dBZe.

SAMPLE VOLUME	SV .25 km/1	N/A A	10

A data sample volume whose dimensions are 1 degree in azimuth, .25 km in range, and 1 degree in depth (perpendicular to the radar beam).

THRESHOLD(Convergence Azimuth)	TCA 4	degrees A	10

A value that represents the maximum azimuthal separation between PATTERN VECTORs (Radial) (4), in degrees.

THRESHOLD(Convergence Range)	TCR 4.0	km A	10

A value that represents the maximum range separation between PATTERN VECTORs (Radial) (4.0), in kilometers.

THRESHOLD(High Convergence Flux)	THCF 361	km**2/hr A	10

A value that represents the minimum magnitude of flux expected in convergence in the presence of minimal shear (361), in km**2/hr.

THRESHOLD(High Gradient)	THG (2.34)	(km/hr)/km A	10

A value that represents the minimum magnitude of Doppler velocity gradient in the presence of minimal convergence flux (2.34), in (km/hr)/km.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
THRESHOLD(Low Convergence Flux)	TLCF 108	km**2/hr A	 10

A value that represents the minimum magnitude of flux expected in convergence (108), in km**2/hr.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
THRESHOLD(Low Gradient)	TLG 1.8	(km/hr)/km A	 10

A value that represents the minimum magnitude of Doppler velocity gradient (1.8), in (km/hr)/km.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
THRESHOLD(PATTERN VECTOR(Radial)Number)	TVVN 10	unitless A	 10

The minimum number of PATTERN VECTOR(Radial) to comprise a feature (10).

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
THRESHOLD(Velocity Number)	TVN 5	km/hr A	 10

The number of Doppler velocities used to calculate running averages (5), in km/hr.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
THRESHOLD(Velocity Reflectivity)	TVR 15	dBZe A	 10

The REFLECTIVITY FACTOR(DBZE) above which Doppler velocities will be processed (15), in dBZe.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
VELOCITY RANGE(Slant)	VRS N/A	km A	 10

The slant range of a VELOCITY VECTOR, in kilometers.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
VELOCITY(Doppler)	VD N/A	km/hr A	10

Doppler velocities in a SAMPLE VOLUME, in km/hr.

VELOCITY(Doppler) average	VDavg N/A	km/hr D	10

The smoothed 5 point average Doppler Velocity, in km/hr.

VELOCITY(Doppler) final	VDfin N/A	km/hr E	10

The smoothed 5 point average Doppler velocity at the end of a PATTERN VECTOR(Radial), in km/hr.

VELOCITY(Doppler) initial	VDini N/A	km/hr E	10

The smoothed 5 point average Doppler velocity at the beginning of a PATTERN VECTOR(Radial), in km/hr.

VELOCITY(Doppler)DIFFERENCE average	VDDavg N/A	km/hr A	10

The average Doppler velocity difference of a FEATURE, in km/hr.

VELOCITY(Doppler)DIFFERENCE maximum	VDDmax N/A	km/hr A	10

The maximum velocity difference of a FEATURE, in km/hr.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
WIDTH	WI N/A	km E	10

The width of a FEATURE, in kilometers.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
WIDTH average	WIavg N/A	km E	10

The average width of a FEATURE, in kilometers.

NEXRAD REVISION DATA ELEMENTS

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ALGORITHM NUMBER 30 - FLASH FLOOD PRECIP. PROJECTION

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
ACCUMULATION SCAN(Scan-to-Scan)	ASSadj	dBA	
adjusted	N/A	A	7

The total scan-to-scan accumulation data on a 1 degree by 2 km polar grid from 1 to 230 km in dBA. This data has been adjusted for the estimated mean field bias. A precision of at least 0.5 dBA and a dynamic range of at least -29 to 26 dBA are required. Includes the previous average TIME(Scan) and current average TIME(Scan).

BEGIN(Time)	TBi	hr	
	N/A	B	6a

Time of start of precipitation at the i-th BOX(1/40th LFM Grid) to the nearest 1/1200 hour.

BIAS	Bcur	unitless	
current	N/A	A	4b

The current multiplicative factor that adjusts for the radar bias when compared to surface precipitation measurement.

BOX(1/40 LFM Grid)	BLM	N/A	
	N/A	A	10

Rectangular grid box centered on 1/40th LFM Grid points. At 60 degrees N, the mesh length is 4.7625 km. Specifies the scan's sample volumes whose centers fall within each grid box. If none, the sample volume whose center is closest to the center of the grid box is specified. Grid boxes whose centers are more than 230 km from the radar are not assigned to any sample volumes.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
CORRELATION(Parameters)	CCP	N/A	
	N/A	B	4a

A normalized procedure which allows the residuals to be directly compared from one scan to the next to derive a single parameter residual decay.

COUNTER(Autocorrelation)	NA	unitless	
	N/A	B	4a

The number of sample values available to compute autocorrelations.

COUNTER(Highest Storm)	NIH	unitless	
	N/A	B	4a

Highest COUNTER(Storm) needed for the projection.

COUNTER(Storm)	NI	unitless	
i-th BOX(1/40th LFM Grid)	N/A	B	4a

The number of time steps since the start of precipitation at LOCbox.

COUNTER(Storm)	NIitemp	unitless	
temporary	N/A	B	4a

Temporary number of time steps since the start of precipitation at LOCboxi.

COUNTER(Storm)	NImax	unitless	
maximum	N/A	B	4a

The largest COUNTER(Storm) since the start of precipitation.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
COUNTER(Storm) Sample Values	CSS	N/A	
	N/A	B	4a

Values computed for the determination of the mean precipitation of a COUNTER(Storm) and its standard deviation.

ERROR VARIANCE	EV	mm**2/hr**2	
grid box observed		B	4a

The observed error variance for the i-th BOX(1/40th LFM Grid)(in mm**2/hr**2). Precise to .1mm**2/hr**2.

ERROR VARIANCE	EVns	unitless	
Number of Samples		B	4a

Number of samples for the grid box observed error variance for the i-th BOX (1/40th LFM Grid).

ERROR VARIANCE	EVsum	mm**2	
sum grid box observed		B	4a

The sum of the grid box observed error variance for the i-th BOX (1/40th LFM Grid) (in mm**2) and associated average TIME(Scan) for each average TIME(Scan) during the past 6 hours. Precise to .1mm**2.

ERROR(Proportion Factor)	EPF	unitless	
	N/A	A	3

Ratio of presumed observational error variance of precipitation rates to local (5 x 5 grids) variance of precipitation rates themselves, unitless.

FLAG(No Projection)	FNP	N/A	
	N/A	A	10

A set or cleared flag for each average TIME(Scan) indicating, if set, that no projection is possible because of insufficient data or the average TIME(Scan) minus TIME(Last Precipitation Detected) is greater than TIME(Reset).

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY	
FLAG(Zero Rate)	FZR N/A	N/A A	10	A set or cleared flag for each average TIME(Scan) indicating, if set, that all precipitation rate values can be assumed to be equal to RATE(Zero Precipitation).
FLAG(Zero Scan-to-Scan)	FZS N/A	N/A A	10	A set or cleared flag indicating, if set, that all current ACCUMULATION SCAN (Scan-to-Scan) values can be assumed to be equal to ACCUMULATION (Zero Interpolated).
INDEX minimum	INXmin	B	9	Computed temporary variable ranging from zero to one less than maximum PROJECTION TIME COUNTER.
INTEGER(Fixed)	FIX N/A	N/A A	10	A function that converts the real argument to an integer number by truncation.
JINDEX	JIN	unitless B	9	Index values that range from 1 to the maximum number of projection time steps in a PROJECTION INTERVAL.
KINDEX	KIN	unitless B	9	Index values that range from JINDEX to the maximum number of projection time steps in a PROJECTION INTERVAL.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY

LAGONE AUTOCORRELATION — L1A — unitless
N/A — B — 4a

LAGONE AUTOCORRELATION of the normalized RESIDUALS.

LAGZERO AUTOCORRELATION — LOA — unitless
N/A — B — 4a

LAGZERO AUTOCORRELATION of the NORMALIZED RESIDUALS.

LINDEX — LIN — unitless
N/A — B — 9

Index values that range from zero to minimum INDEX.

LOCATION boxi — LOCboxi — N/A
N/A — A — 10

Refers to the BOX location within this grid.

MULTIMATRIX — MTXmulti — N/A
N/A — B — 4a

A modified correlation matrix containing the correlation of errors for each projected RATE with every other projected RATE modified for efficiency of transformation into a covariance matrix and summation of all terms in the covariance matrix.

NUMBER of SAMPLES — NS — unitless
N/A — B — 4a

Number of samples for COUNTER(Storm) NI.

NAME	SYMBOL	UNITS	
	VALUE	CLASS	CATEGORY

NUMBER of SAMPLES	NStemp	N/A	
temporary	N/A	B	4a

Temporary number of samples for COUNTER(Storm) NI.

PRECIPITATION ACCUMULATION	PAproj	mm	
projected	N/A	E	7

Projected accumulation for the i-th BOX (1/40th LFM Grid) (in mm). Precise to .1mm.

PRECIPITATION ACCUMULATION	PAtot	mm	
total storm	N/A	E	7

The total storm precipitation accumulation in each 1/40th LFM Grid box. The total storm precipitation accumulation refers to the sum of the total observed precipitation accumulation at the current average TIME(Scan) and the projected precipitation. Precise to .1mm.

PRECIPITATION ACCUMULATION	PAtotobs	mm	
total observed	N/A	E	7

Total observed precipitation accumulation (adjusted for the estimated mean field bias) for the i-th BOX (1/40th LFM Grid) (in mm) and associated average TIME(Scan), for each average TIME(Scan) during the past 6 hours. Precise to .1mm.

PROJECTED RATE(Precipitation)	PRtot	mm/hr	
total	N/A	B	4a

Total projected RATE(Precipitation) for the i-th BOX (1/40th LFM Grid). Precise to .1mm/hr.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
PROJECTION INTERVAL	LPR 0.5-2.0	hr A	3

An even multiple of the projection time step for a given projection precipitation (in hours) to the nearest 1/1200th hour. (0.5-2.0).

PROJECTION PARAMETER	PP N/A	unitless B	4a

A single parameter residual decay that allows the residuals to be directly compared from one scan to the next.

PROJECTION TIME COUNTER	PRC N/A	unitless B	4a

The number of projection time steps in a PROJECTION INTERVAL.

PROJECTION TIME COUNTER maximum	PRCmax N/A	unitless B	4a

The maximum number of projection time steps in a PROJECTION INTERVAL.

PROJECTION TIME STEP(Hours)	Δt N/A	hr A	6a

Projection time step(hours) to the nearest 1/1200 hour.

RATE SCAN	RSP N/A	dBR A	7

Precipitation rate data on a 1 degree by 2 km polar grid from 1 to 230 km, in dBR. A precision of at least 0.5 dBR and a dynamic range of at least -18 to 32 dBR are required (not generated for times when FLAG(Zero Rate) are set).

NAME	SYMBOL	UNITS	
	VALUE	CLASS	CATEGORY

RATE(Mean)	MRn	mm/hr	
	N/A	B	7

Mean(RATE) for Storm COUNTER NI (in mm/hr). Precise to .1mm/hr.

RATE(Precipitation)	RRevar	mm/hr	
error variance	N/A	B	4a

Total RATE of precipitation for the 25 Boxes surrounding the i-th BOX (1/40th LFM Grid) for the grid box observed error variance (in mm/hr). Precise to .1mm/hr.

RATE(Precipitation)	RRiadj	mm/hr	
adjusted	N/A	B	4a

RATE (adjusted for radar bias) of precipitation of the i-th BOX(1/40th LFM Grid) in the current scan (in mm/hr). Precise to .1mm/hr.

RATE(Precipitation)	RRiproj	mm/hr	
projected	N/A	B	4a

Projected RATE (adjusted for radar bias) of precipitation for Storm COUNTER N (in mm/hr). Precise to .1mm/hr.

RATE(Precipitation)	RRn	mm/hr	
total	N/A	B	4a

Total RATE of precipitation for COUNTER(Storm) NI (in mm/hr). Precise to .1mm/hr.

RATE(Precipitation)	RRsqr	(mm/hr)**2	
squared	N/A	B	4a

Squared total RATE of precipitation for COUNTER(Storm) NI (in(mm/hr)**2). Precise to .1(mm/hr)**2.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
RATE(Precipitation) squared error variance	RRsqrevar N/A	mm**2/hr**2 B	 4a

Total squared RATE (Precipitation) for the 25 Boxes surrounding the i-th BOX (1/40th LFM Grid) for the grid box observed error variance (in mm**2/hr**2). Precise to .1mm**2/hr**2.

RATE(Precipitation) temporary	RRtemp N/A	mm/hr B	 4a

Temporary total RATE of precipitation for COUNTER (STORM) NI (in mm/hr). Precise to .1mm/hr.

RATE(Precipitation) temporary squared	RRtempsqr N/A	(mm/hr)**2 B	 4a

Temporary squared total RATE(Precipitation) for COUNTER (Storm) NI (in (mm/hr)**2). Precise to .1(mm/hr)**2.

RATE(Standard Deviation)	SDn N/A	mm/hr B	 4a

The standard deviation of the rate for COUNTER(Storm) NI (in mm/hr). Precise to .1mm/hr.

RESIDUAL(Normalized) current	NRTicur N/A	unitless B	 4a

Normalized RESIDUAL at the i-th BOX for the current scan.

RESIDUAL(Normalized) previous	NRTipre N/A	unitless B	 4a

Normalized RESIDUAL at the i-th BOX for the previous scan.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
RESIDUAL(Normalized) temporary	NRTitemp N/A	unitless B	 4a

Temporary normalized RESIDUAL for the i-th BOX(1/40th LFM Grid).

SAMPLE SIZE(Counter)	SM6 N/A	unitless B	 4a

Sample size counter for storm INITIATION SUMs.

SAMPLE VALUES grid box	SVA N/A	unitless B	 4a

Values computed for the determination of the grid box observed error variance.

STORM DYNAMICS(Multi COUNTER (Storm) Method)	SDM N/A	N/A B	 4a

A computation that determines the mean precipitation and standard deviation of a COUNTER(Storm), that does not meet the initial THRESHOLD(Minimum NUMBER of SAMPLES) criteria by adding samples from adjacent COUNTER (Storm) until the THRESHOLD(Minimum NUMBER of SAMPLES) is met.

STORM DYNAMICS(Projected)	STP N/A	N/A B	 4a

States that the mean and standard deviation for all COUNTERS(Storm) beyond the maximum available COUNTER (Storm) are presumed equal to the maximum available COUNTER(Storm) (simple persistence).

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
STORM DYNAMICS(Single COUNTER (Storm) Method)	SDS N/A	N/A B	4a

A computation that determines the mean precipitation of a COUNTER(Storm) and its standard deviation, if the THRESHOLD(Minimum NUMBER of SAMPLES) is met.

STORM INITIATION DECAY	SID 0.8-1.0	weight A	3

A decay parameter which determines the weight to be placed on previous storm motion information (0.8-1.0).

STORM INITIATION OFFSET max. negative Y-direction	OFmny N/A	unitless B	4a

Maximum Storm Initiation Offset (negative Y-direction).

STORM INITIATION OFFSET max. positive Y-direction	OFmpy N/A	unitless B	4a

Maximum Storm Initiation Offset (Positive Y-direction).

STORM INITIATION OFFSET X-direction	OFx N/A	unitless B	4a

Storm Initiation offset, (X-direction).

STORM INITIATION OFFSET Y-direction	OFy N/A	unitless B	4a

Storm Initiation Offset, (Y-direction).

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
STORM INITIATION OFFSET LIMITS	DYP	unitless	
	N/A	B	4a

Storm Initiation Offset Limits in the Y-direction.

STORM INITIATION OFFSET TIME	TOF	unitless	
	N/A	B	4a

Values of the Storm Initiation Offset time are integers ranging from zero to the number of time steps for which the storm projection is made. They are uniformly distributed (approximately) so that the number of entries in the Storm Initiation Offset table with any particular value of the Storm Initiation Offset time will approximately be the number of storm Initiation Offsets divided by the quantity (number of time steps plus 1).

STORM INITIATION PARAMETERs	IP1,IP2	unitless	
	N/A	B	4a

Storm INITIATION PARAMETERs (IP1 and IP2).

STORM INITIATION SUM	SM1-SM5,SM7,SM8	unitless	
	N/A	B	4a

Storm INITIATION SUMs (SM1-SM5,SM7,SM8).

STORM INITIATION WIDTH	D	N/A	
	1-2	A	3

This is the width of the rectangular region (searched "upwind") for storm initiation, measured in units of grid spacing (1-2).

SUM1	SUM1		
	N/A	B	4b

A computed temporary variable used to compute the terms in MULTIMATRIX.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
TARGET BOX	TBX N/A	N/A A	10

These are the boxes searched for "upwind" of the grid box with a COUNTER(Storm) of zero. These boxes are searched for "upwind" until precipitation is detected at the TARGET BOX. The OFx, OFy and TOF from this TARGET BOX to the grid box with a COUNTER(Storm) of zero is obtained from the storm initiation offset table.

TEMPORARY SUM	TS1-TS7 N/A	unitless B	4a

TEMPORARY SUMs (TS1 - TS7) used in Storm initiation computation.

THRESHOLD(Minimum NUMBER of SAMPLES)	TMN N/A	N/A A	3

Minimum NUMBER of SAMPLES needed for a valid statistical analysis.

TIME(End)	TENi N/A	hr A	6a

Ending time of precipitation at the i-th BOX(1/40th LFM Grid) to the nearest 1/1200 hour.

TIME(Expired)	TEXi N/A	hr B	6b

Time for the i-th BOX(1/40th LFM Grid) since last precipitation to the nearest 1/1200 hour.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
TIME(Last Precipitation Detected)	TLD	absolute time	
	N/A	A	6a

The time at which the Precipitation Detection support function last detected precipitation. A precision of at least 1/1200 hour is required.

TIME(Reset)	TRT	hr	
	1-2	A	3

Maximum time allowed for no precipitation before parameters are reset (1-2), in hours.

TIME(Scan)	TSavg	hr	
average	N/A	A	6a

The average scan time of the four elevation scans used to construct the HYBRID SCAN. A precision of at least 1/1200 hours and accuracy to within 1/120 hours are required. This is a time of occurrence, not duration.

TIME(Scan)	TSavgpre	hr	
average previous	N/A	B	6a

Average TIME(Scan) of the previous RATE scan to the nearest 1/1200 hour.

TIME(Scan)	TSproj	hr	
projected	N/A	E	6a

Average TIME(Scan) for projected RATE scan to the nearest 1/1200 hour.

VARIANCE	VNCproj	mm**2	
projected	N/A	B	4a

Projected variance for that COUNTER (Storm) (in mm**2). Precise to .1mm**2.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
VARIANCE	VNCtempproji	mm**2	
temporary projected	N/A	B	4a

The temporary projected variance for the i-th BOX (1/40th LFM Grid)(in mm**2). Precise to .1mm**2.

VARIANCE	VNCtot	mm**2	
total	N/A	E	7

The total variance in the i-th BOX(1/40th LFM Grid). It is the summation of the sum of grid box observed error variance at the current average TIME(Scan) and the projected variance (in mm**2). Precise to .1mm**2.

VARIANCE	VNCtotproji	mm**2	
total projected	N/A	B	4a

Projected variance for the i-th BOX (1/40th LFM Grid) (in mm**2). Precise to .1mm**2.

VARIANCE	VNCvarsum(n)	mm**2	
sum projected	N/A	B	4a

The projected variance sum of COUNTER(Storm) NI (in mm**2). Precise to .1mm**2.

X-COORDINATE	XI	unitless	
	-66 to 66	A	10

X-coordinate location of i-th BOX(1/40th LFM Grid). Values range from -66 to 66 with the radar located within the BOX such that XI = 0.

Y-COORDINATE	YI	unitless	
	-66 to 66	A	10

Y-coordinate location of i-th BOX(1/40th LFM Grid). Values range from -66 to 66 with the radar located within the BOX such that YI = 0.

NEXRAD REVISION DATA ELEMENTS

SORTED BY NAME

ALGORITHM NUMBER 31 - FLASH FLOOD POTENTIAL ASSESSMENT

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
ERROR VARIANCE	EVsum	mm**2	
sum of grid box observed	N/A	B	4a

The sum of the grid box observed error variance for the i-th BOX (1/40th LFM Grid) (in mm**2) and associated average TIME(Scan) for each average TIME(Scan) during the past 6 hours. Precise to .1mm**2.

FLAG(No Projection)	FNP	N/A	
	N/A	A	10

A set or cleared flag for each average TIME(Scan) indicating, if set, that no projection is possible because of insufficient data or the average TIME(Scan) minus TIME(Last Precipitation Detected) is greater than TIME (Reset).

FLASH FLOOD PROBABILITY	FFPmaxobs	percent	
maximum observed	N/A	E	7

The maximum observed flash flood probability for all Guidance Durations for the i-th BOX (1/40th LFM Grid) (in percent). Precise to .02 percent.

FLASH FLOOD PROBABILITY	FFPmaxproj	percent	
maximum projected	N/A	E	7

The maximum projected flash flood probability of a particular Guidance Duration for the i-th BOX (1/40th LFM Grid) (in percent). Precise to .02 percent.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
FLASH FLOOD PROBABILITY	FFPobs	percent	
observed	N/A	B	4a

The observed flash flood probability for the i-th BOX (1/40th LFM Grid) for a particular Guidance Duration (in percent). Precise to .02 percent.

FLASH FLOOD PROBABILITY	FFPproj	percent	
projected	N/A	B	4a

The projected flash flood probability for the i-th BOX (1/40th LFM Grid) for Guidance Duration (in percent). Precise to .02 percent.

FLASH FLOOD PROBABILITY	FFPzonmaxobs	percent	
zonal maximum observed	N/A	E	7

The maximum observed flash flood probability among all Guidance Durations and all Boxes (1/40th LFM Grid) in the j-th Zone (in percent). Precise to .02 percent.

FLASH FLOOD PROBABILITY	FFPzonmaxproj	percent	
zonal maximum total storm	N/A	E	7

The maximum total storm flash flood probability among all Guidance Durations and all BOXes (1/40th LFM Grid) in the j-th Zone (in percent). Precise to .02 percent.

FLASH FLOOD(Guidance Table)	FFG	unitless	
	N/A	A	10

A table composed of three columns: (1) FLASH FLOOD (Zone) (2) FLASH FLOOD(Guidance Value) (3) FLASH FLOOD (Guidance Duration). Each entry in the table gives a rainfall accumulation in mm (the Guidance Value) which will cause flash flooding within a particular geographc area (the Zone) if it occurs over a particular duration in hours (the Guidance Duration). The FLASH FLOOD (Guidance Table) is produced at the River

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
FLASH FLOOD(Guidance Table)(Con't)	FFG N/A	unitless A	10

Forecast Centers (currently once a day) and communicated to the RPG using the existing rain gage data acquisition port.

FLASH FLOOD(Guidance Value)	FFGV N/A	inches A	10

The flash flood Guidance Value is the amount of rainfall over a specified duration required to produce flooding (in inches). Precise to 0.1 inch.

OBSERVED ERROR VARIANCE	OEV N/A	mm**2 B	4a

The observed error variance for the i-th BOX (1/40th LFM Grid) for a particular Guidance Duration (in mm**2). Precise to .1mm**2.

PRECIPITATION ACCUMULATION zon max tot storm (G. D.)	PAmaxtotaccum N/A	mm E	7

The maximum total storm precipitation accumulation for a particular Guidance Duration for the j-th Flash Flood Guidance Zone (in mm). Precise to .1mm.

PRECIPITATION ACCUMULATION observed	PAobs N/A	mm B	4a

Observed precipitation accumulation for the i-th BOX (1/40th LFM Grid) for a particular Guidance Duration (in mm). Precise to .1mm.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
PRECIPITATION ACCUMULATION	PAtot	mm	
total storm	N/A	B	4a

The total storm precipitation accumulation in each 1/40th LFM Grid box. The total storm precipitation accumulation refers to the sum of the total observed precipitation accumulation at the current average TIME(Scan) and the projected precipitation (in mm). Precise to .1mm.

PRECIPITATION ACCUMULATION	PAtotaccum	mm	
tot storm guid duration	N/A	B	4a

The total storm precipitation accumulation for the i-th BOX (1/40th LFM Grid) for a particular Guidance Duration (in mm). Includes the projected accumulations for the entire projection period plus observed accumulations. Precise to .1mm.

PRECIPITATION ACCUMULATION	PAtotobs	mm	
total observed	N/A	B	4a

Total observed precipitation accumulation (adjusted for the estimated mean field bias) for the i-th BOX (1/40th LFM Grid) (in mm) and associated average TIME(Scan) for each average TIME(Scan) during the past 6 hours. Precise to .1mm.

PRECIPITATION ACCUMULATION	PAzonmaxobs	mm	
zonal maximum observed	N/A	E	7

The maximum observed precipitation accumulation for a particular Guidance Duration for the j-th Flash Flood Guidance Zone (in mm). Precise to .1mm.

VARIANCE	VNCtot	mm**2	
total	N/A	E	4a

The total variance in each i-th BOX (1/40th LFM Grid). It is the summation of the sum of grid box observed error variance at the current average TIME(Scan) and the projected variance (in mm**2). Precise to .1mm**2.

NAME	SYMBOL	UNITS	
	VALUE	CLASS	CATEGORY
VARIANCE	VNCtotgvd	mm**2	
total guidance value	N/A	B	4a

The total variance for the i-th BOX (1/40th LFM Grid) for a particular Guidance Duration (in mm**2). Precise to .1mm**2.

NEXRAD REVISION DATA ELEMENTS

SORTED BY NAME

ALGORITHM NUMBER 33 - COMBINED SHEAR

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
AZIMUTH	AZ N/A	radians A	2

Azimuthal position, in radians. Precise to 1/10**2 radians.

AZIMUTH maximum	AZmax N/A	radians C	4a

Maximum azimuth angle to be processed. Value determined by the Cartesian grid specification, in radians. Precise to 1/10**2 radians.

AZIMUTH minimum	AZmin N/A	radians C	4a

Minimum azimuth angle to be processed. Value determined by the Cartesian grid specification, in radians. Precise to 1/10**2 radians.

AZIMUTH LIMITS	AZA1-AZA4 N/A	radians C	4a

Azimuth angles to the vertices of the Cartesian grid, with the radar as the origin.

COMBINED SHEAR	COSH N/A	1/hr B	4a

Combined shear as computed from the mean radial shear and the mean azimuthal shear, in 1/hr.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
COUNT FILTER(Azimuthal)	CFLA N/A	N/A B	10

Count of the number of (mean SHEAR(Azimuthal)) values used in filter for current point being filtered. This value will always be less than or equal to NUMBER (Filter).

COUNT FILTER(Radial)	CFLR N/A	N/A B	10

Count of the number of (mean SHEAR(Radial)) values used in filter for current point being filtered. This value will always be less than or equal to NUMBER (Filter).

DIFFERENCE(Azimuthal)	DA N/A	N/A C	5b

Differences in average VELOCITY(Doppler) computed between adjacent azimuths and at constant range.

DIFFERENCE(Radial)	DR N/A	N/A C	5b

Radial differences in average VELOCITY (Doppler) computed between sample volumes spaced NUMBER(Sample Volumes) apart and at constant azimuth.

DOMAIN(Resolution)	DOR 0.5-4.0	km A	4b

Grid point spacing for the Cartesian grid, in km (0.5-4.0).

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
DOMAIN(X Minimum)	DXM N/A	km A	4b

The lower left X(W-E) coordinate relative to the radar for the rectangular Cartesian grid for the interpolated shears, in km.

DOMAIN(X Size)	DXS 230	km A	4b

Length of the (W-E) side of the Cartesian grid box, in km (230). Note: The box is centered on the radar.

DOMAIN(Y Minimum)	DYM N/A	km A	4b

The lower left Y(S-N) coordinate relative to the radar for the rectangular Cartesian grid for the interpolated shears, in km.

DOMAIN(Y Size)	DYS 230	km A	4b

Length of the (S-N) side of the Cartesian grid box, in km (230). Note: The box is centered on the radar.

ELEVATION	PHI# N/A	radians A	2

Elevation angle, in radians. Precise to 1/10**2 radians.

FLAG VALUE	FLV N/A	unitless A	3

Default value for filtered SHEAR(Radial-RSA), filtered SHEAR (Azimuthal) and COMBINED SHEAR.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
MAXIMUM SAMPLES(Radial)	MSR N/A	unitless C	4a

The maximum number of SAMPLE VOLUMES in one radial.

NUMBER(Azimuthal Difference)	NAD N/A	N/A C	4a

Number of azimuthal shear values accumulated at each grid point.

NUMBER(Filter)	NFL 9	unitless A	3

Number of data points used in the uniform filter applied to the mean SHEAR(Azimuthal) and mean SHEAR (Radial) fields (9).

NUMBER(Good Radial Velocities)	NGR N/A	N/A C	4a

Number of good radial velocity values which have gone into the corresponding average VELOCITY(Doppler) computation.

NUMBER(Potential Difference Azimuthal)	NPDA N/A	N/A C	4a

Total number of DIFFERENCE(Azimuthal) values that could potentially contribute to the COMBINED SHEAR, at each grid point if all acceptance criteria are met.

NUMBER(Potential Difference Radial)	NPDR N/A	N/A C	4a

Total number of DIFFERENCE(Radial) values that could potentially contribute to the COMBINED SHEAR at each grid point if all acceptance criteria are met.

NAME	SYMBOL	VALUE	UNITS	CLASS	CATEGORY	
NUMBER(Radial Difference)	NRD	N/A	N/A	C	4a	Number of radial shear values accumulated at each grid point.
NUMBER(Sample Volumes)	NSV	3	unitless	A	3	Number of contiguous SAMPLE VOLUMEs to be averaged to produce each estimate of average VELOCITY(Doppler) (3). Also used in determining the difference distance for the radial shear computations.
POWER	POW	N/A	dBm	A	2	Received power for each SAMPLE VOLUME, in dBm.
RANGE LIMITS	R1,R2,R3,R4	N/A	N/A	C	4a	Ranges from the radar to the vertices of the Cartesian grid.
RANGE SAMPLE SPACING azimuth	RSSazi	N/A	km	A	3	Differences in range between two adjacent SAMPLE VOLUMEs along an azimuth, in kilometers. Precise to 1/10**2 km.
RANGE(Slant)	RS	N/A	km	C	4a	The slant range to the center of a SAMPLE VOLUME, in kilometers. Precise to 1/10**2 km.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
RANGE(Slant) maximum	RSmax N/A	km C	4a

Maximum range for which the data are to be processed. Value determined by the Cartesian grid specification, in kilometers. Precise to 1/10**2 km.

RANGE(Slant) minimum	RSmin N/A	km C	4a

Minimum range for which the data are to be processed. Value determined by the Cartesian grid specification, in kilometers. Precise to 1/10**2 km.

SHEAR(Azimuthal) filtered	SAfilter N/A	N/A C	4a

Shear values derived by imposing an uniform filter to the field of mean SHEAR(Azimuthal) values.

SHEAR(Azimuthal) mean	SAmean N/A	N/A C	4a

Normalized SUM (Azimuthal Difference) values at each grid point.

SHEAR(Radial-RSA) filtered	SRfilter N/A	N/A C	4a

Shear values derived by imposing an uniform filter to the field of mean SHEAR (Radial) values.

SHEAR(Radial-RSA) mean	SRmean N/A	N/A C	4a

Normalized SUM (Radial Difference) values at each grid point.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY	
SUM(Azimuthal Difference)	SAD N/A	N/A C	4a	Sum of the azimuthal differences at each Cartesian grid point.
SUM(Radial Difference)	SRD N/A	N/A C	4a	Sum of the radial differences at each Cartesian grid point.
THRESHOLD (Number)	NTH .75	unitless A	3	The minimum fraction of NUMBER(Radial Difference) to NUMBER(Potential Difference Radial) and of NUMBER (Azimuthal Difference) to NUMBER (Potential Difference Azimuthal) for the calculations of the respective shears (.75).
THRESHOLD(Combined Shear)	THCS 8-16	1/hr A	3	The minimum combined shear value allowed for acceptance in the final shear field, in 1/hr (8-16).
THRESHOLD(Velocity Power)	TPOW 5-10	dB A	3	The received power above which velocities will be processed, in dB (5-10).
VELOCITY(Doppler)	VD km/hr	km/hr A	2	Doppler velocities in a SAMPLE VOLUME, in km/hr.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
RANGE(Slant) maximum	RSmax N/A	km C	4a
Maximum range for which the data are to be processed. Value determined by the Cartesian grid specification, in kilometers. Precise to 1/10**2 km.			
RANGE(Slant) minimum	RSmin N/A	km C	4a
Minimum range for which the data are to be processed. Value determined by the Cartesian grid specification, in kilometers. Precise to 1/10**2 km.			
SHEAR(Azimuthal) filtered	SAfilter N/A	N/A C	4a
Shear values derived by imposing an uniform filter to the field of mean SHEAR(Azimuthal) values.			
SHEAR(Azimuthal) mean	SAmean N/A	N/A C	4a
Normalized SUM (Azimuthal Difference) values at each grid point.			
SHEAR(Radial-RSA) filtered	SRfilter N/A	N/A C	4a
Shear values derived by imposing an uniform filter to the field of mean SHEAR (Radial) values.			
SHEAR(Radial-RSA) mean	SRmean N/A	N/A C	4a
Normalized SUM (Radial Difference) values at each grid point.			

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
SUM(Azimuthal Difference)	SAD N/A	N/A C	4a

Sum of the azimuthal differences at each Cartesian grid point.

SUM(Radial Difference)	SRD N/A	N/A C	4a

Sum of the radial differences at each Cartesian grid point.

THRESHOLD (Number)	NTH .75	unitless A	3

The minimum fraction of NUMBER(Radial Difference) to NUMBER(Potential Difference Radial) and of NUMBER (Azimuthal Difference) to NUMBER (Potential Difference Azimuthal) for the calculations of the respective shears (.75).

THRESHOLD(Combined Shear)	THCS 8-16	1/hr A	3

The minimum combined shear value allowed for acceptance in the final shear field, in 1/hr (8-16).

THRESHOLD(Velocity Power)	TPOW 5-10	dB A	3

The received power above which velocities will be processed, in dB (5-10).

VELOCITY(Doppler)	VD km/hr	km/hr A	2

Doppler velocities in a SAMPLE VOLUME, in km/hr.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY	
VELOCITY(Doppler) average	VDavg N/A	km/hr C	4a	Running average in range of radial velocity, in km/hr.
X-DIMENSION	XDIM N/A	unitless A	3	The integral number of grid locations in the x-direction of the grid as determined by DOMAIN(X Size) and DOMAIN(Resolution).
X-INDEX azimuthal	XINazi N/A	N/A C	9	X-index corresponding to the transformation of the DIFFERENCE (Azimuthal) values in polar coordinates to the rectangular Cartesian coordinate system used for the shear fields.
X-INDEX radial	XINrad N/A	N/A C	9	X-index corresponding to the transformation of the DIFFERENCE (Radial) values in polar coordinates to the rectangular Cartesian coordinate system used for the shear fields.
Y-DIMENSION	YDIM N/A	unitless A	3	The integral number of grid locations in the y-direction of the grid as determined by DOMAIN(Y Size) and DOMAIN(Resolution).

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
Y-INDEX azimuthal	YINDazi N/A	N/A C	9

Y-index corresponding to the transformation of the DIFFERENCE (Azimuthal) values in polar coordinates to the rectangular Cartesian coordinate system used for the shear fields.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
Y-INDEX radial	YINDrad N/A	N/A C	9

Y-index corresponding to the transformation of the DIFFERENCE(Radial) values in polar coordinates to the rectangular Cartesian coordinate system used for the shear fields.

NEXRAD REVISION DATA ELEMENTS

SORTED BY NAME

ALGORITHM NUMBER 34 - CROSS-CORRELATION TRACKING

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
COLUMN DISPLACEMENT(Correlation Maximum)	DPCM N/A	correlation pixels C	 8

Column displacement of the correlation box in LAYER (Previous) yielding the maximum value of CORRELATION (Box Displacement), units of correlation pixels. Precise to 1 correlation pixel.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
COLUMN DISPLACEMENT(Interpolated)	DPCI N/A	correlation pixels B	 4a

Quadratic estimate of peak location in correlation surface sampled in FIELD (Correlation) in the column dimension, units of correlation pixels. Precise to 1/10**4 correlation pixels.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
COLUMN VELOCITY	VELC N/A	km/hr C	 8

Correlation-based estimate of the velocity of a correlation box in the column dimension of LAYER (Previous), units of km/hr. Precise to 1/10**3 km/hr.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
CORRELATION(Box Displacement)	COC N/A	unitless B	 4a

The coefficient of correlation between the threshold data of a correlation box in LAYER(Previous) and an equally-sized array of data in LAYER(Current). Precise to 1/10**6 units.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
DISTANCE SQUARED(Box)	DSQB N/A	km**2 B	5b

The distance, squared, from the correlation box with undetermined velocities in Section 6.0 of the algorithm to a correlation box whose velocities were computed in Section 5.0, units of km**2. Precise to 0.1 km**2.

DISTANCE(Maximum Lag)	DML N/A	correlation pixels D	10

The displacement of an object moving at SPEED(Storm Limit) for a time interval equal to that between LAYER (Previous) and LAYER(Current), units of correlation pixels. Precise to 1 correlation pixel.

FIELD(Correlations)	FLC N/A	unitless C	7

An array of the same dimensions, spatial resolution and orientation as the correlation box subarrays of LAYER (Previous), containing the field of CORRELATION(Box Displacement) computed for this correlation box. Precise to 1/10**6 units for each entry.

INTERPOLATED VELOCITY(Column)	IVEC N/A	km/hr C	8

The interpolated, column-dimension, velocity of a correlation box, computed in the absence of a correlation-based velocity, units of km/hr. Precise to 1/10**3 km/hr.

INTERPOLATED VELOCITY(Row)	IVER N/A	km/hr C	8

The interpolated, row-dimension, velocity of a correlation box, computed in the absence of a correlation-based velocity, units of km/hr. Precise to 1/10**3 km/hr.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
LAYER(Current)	LAYC N/A	dBZe A	10

Layered reflectivity product generated from the volume scan immediately prior to the time that the algorithm is invoked - a uniform, horizontal cartesian grid of reflectivity pixels for any of the altitude extents available for the LAYER COMPOSITE REFLECTIVITY product, as specified by TYPE (Layer), units of dBZe. Precise to 1.0 dBZe for each entry.

LAYER(Previous)	LAYP N/A	dBZe A	10

Layered reflectivity product of the same TYPE (Layer) and format as LAYER (Current), but generated from the volume scan preceding that of LAYER (Current), units of dBZe. Precise to 1.0 dBZe for each entry.

LENGTH(Correlation Box)	LEC 28.0	km A	10

The desired length of a side of a correlation box, units of kilometers (28.0). Precise to 1.0 km.

OVERLAP	OVE N/A	correlation pixels D	10

The overlap in either dimension of LAYER(Previous), of correlation boxes, units of correlation pixels. Precise to 1 correlation pixel.

PIXEL NUMBER	PIX N/A	correlation pixels A	10

The number of correlation pixels to a side of a correlation box. Precise 1 correlation pixel.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
PIXEL SIZE	PS N/A	km A	10

Length of the side of a pixel in the LAYERs, units of kilometers. Precise to 1/10**3 km.

REFLECTIVITY(Pixel)	ZPI N/A	dBZe A	10

Reflectivity value of a pixel in LAYER(Previous) or LAYER(Current), units of dBZe. Precise to 1.0 dBZe.

ROW DISPLACEMENT(Correlation Maximum)	DPRM N/A	correlation pixels C	8

Row displacement of the correlation box in LAYER (Previous) yielding the maximum value of CORRELATION (Box Displacement), units of correlation pixels. Precise to 1 correlation pixel.

ROW DISPLACEMENT(Interpolated)	DPRI N/A	correlation pixels B	4a

Quadratic estimate of peak location in correlation surface sampled in FIELD (Correlation) in the row dimension, units of correlation pixels. Precise to 1/10**4 correlation pixels.

ROW VELOCITY	VELR N/A	km/hr C	8

Correlation-based estimate of the velocity of a correlation box in the row dimension of LAYER(Previous), units of km/hr. Precise to 1/10**3 km/hr.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
SPACING(Correlation Box)	SPC 28.0	km A	10

The desired spacing of correlation box centers in the row and column dimensions of LAYER(Previous), units of km (28.0). Precise to 0.1 km.

SPEED(Storm Limit)	SPL 120.0	km/hr A	10

Maximum possible speed for reflectivity features in LAYER(Previous), units of km/hr (120.0). Precise to 1.0 km/hr.

THRESHOLD(Correlation)	THCO .55	N/A A	3

Minimum value of a correlation coefficient to be accepted for displacement calculations (.55).

THRESHOLD(Good Pixels)	TGP N/A	Correlation Pixels B	4a

THRESHOLD(Pixel Fraction) normalized by the number of pixels in a correlation box, units of correlation pixels. Precise to 1 correlation pixel.

THRESHOLD(Pixel Fraction)	TPF 0.25	unitless A	10

The minimum fraction of above-THRESHOLD (dBZe) Pixels required in a LAYER(Previous) correlation box for a correlation-based displacement to be computed for that Box (0.25). Precise to 1/10**3 units.

NAME SYMBOL UNITS
VALUE CLASS CATEGORY

THRESHOLD(dBZe) THDB dBZe
25.0 A 3

Reflectivity threshold employed in creating binary fields from the two LAYERs, units of dBZe (25.0).

THRESHOLDED PIXEL (Current) ZTPC unitless
N/A B 4b

The thresholded (i.e. zero or one) reflectivity value of the correlation pixel in LAYER (Current) overlaid by the correlation pixel with value ZTPP in the current correlation box of LAYER (Previous) at its current displacement. Precise to 1 unit.

THRESHOLDED PIXEL(Previous) ZTPP unitless
N/A B 4b

The thresholded (i.e. zero or one) reflectivity value of a correlation pixel in the current correlation box of LAYER(Previous). Precise to 1 unit.

TIME(Current) TCUR hr
N/A C 10

The time at which the volume scan generating LAYER (Current) was collected, units of hr. Precise to 1/10**5 hr.

TIME(Previous) TPRE hr
N/A C 10

The time at which the volume scan generating LAYER (Previous) was collected, units of hr. Precise to 1/10**5 hr.

NAME	SYMBOL VALUE	UNITS CLASS	CATEGORY
TYPE(Layer)	TYLA N/A	N/A A	 10

Indicates which of the available altitude regimes for the LAYER COMPOSITE REFLECTIVITY product is desired for LAYER (Current) and LAYER (Previous).

VELOCITIES(Correlation)	VEL N/A	km/hr, km/hr E	 10

A table containing the coordinates, (km East of radar, km North of radar), of each correlation box's center as well as its velocity estimates (km/hr East, km/hr North). Position is precise to 0.1 km East and 0.1 0.1 km North for each entry. Velocity is precise to 1/10**3 km/hr East and 1/10**3 km/hr North for each entry.

APPENDIX C

NEXRAD Algorithm Adaptable Parameters

NEXRAD Algorithm Adaptable Parameters

This Appendix contains the minimum list of algorithm parameters that are to be site-adaptable for each NEXRAD. These parameters will be adjusted to the particular climatology of each site to maximize algorithm performance. As these algorithms have not been tested at all the sites where they will eventually be implemented, a maximum of flexibility is needed to reduce system implementation risk.

Where appropriate and possible default values and/or ranges of values have been listed for each parameter. In some cases, testing has shown no definite preferred value. In other cases, no values are listed because testing is incomplete. It is anticipated that many additions and changes will be made to these values during the NEXRAD system lifetime.

NEXRAD: ADAPTABLE PARAMETERS

SORTED BY ALGORITHM NUMBER THEN NAME

ALGORITHM NO	PARAMETER NAME	SYMBOL	UNITS	TEST VAL/RANGE	EST VAL/RANGE
2	THRESHOLD(Far Maximum Ratio)	TFR	unitless	4.0	
2	THRESHOLD(Far Minimum Ratio)	TRF	unitless	1.6	
2	THRESHOLD(Feature Height)	TFH	km		8
2	THRESHOLD(High Momentum)	THM	km**2/hr	540.0	
2	THRESHOLD(Low Momemtum)	TLM	km**2/hr	180	
2	THRESHOLD(Maximum Ratio)	TMR	unitless	2.0	
2	THRESHOLD(Mesocyclone Azimuth)	TMA	radians	0.034	
2	THRESHOLD(Mesocyclone-High Shear)	TMHS	1/hr	14.4	
2	THRESHOLD(Mesocyclone-Low Shear)	TMLS	1/hr	7.2	
2	THRESHOLD(Minimum Ratio)	TRM	unitless	0.5	
2	THRESHOLD(Pattern Vector)	TPV	unitless	10.0	
2	THRESHOLD(Radial Distance)	TRD	km	0.75	
2	THRESHOLD(Range)	TRA	km	140.0	
4	CORRELATION (Speed)	CS	km/hr	120	
4	RATIO(Minimum)	RATM	unitless	10	
4	SPEED(Minimum)	SPDM	km/hr		2
5	ADJACENCY(Minimum)	ADJmin	unitless	1	
5	THRESHOLD(Overlap)	TOV	unitless	2	
5	THRESHOLD(Segment Length)	TSL	km	4.2	5
7	FIT TESTS	FT	unitless	2	
7	THRESHOLD(Begin Azimuth)	TBZ	radians		
7	THRESHOLD(Data Points)	TDP	unitless	25	
7	THRESHOLD(End Azimuth)	TEZ	radians		
7	THRESHOLD(Symmetry)	THY	km/hr	25.2	
7	THRESHOLD(Velocity)	THV	km/hr	18	
7	VAD RANGE	VAD	km		
8	ALLOWABLE ERRORS	AER	km		30, 60, 90, 120
8	ERROR INTERVAL	EI	hr	.25	
8	FORECAST INTERVALS	FI	hr		.25, .50, .75, 1.0
11	BOX	BOX	unitless		
11	BOX OVERLAP	TBO	percent	50	
12	DEFAULT(Direction)	DDI	radians		
12	DEFAULT(Speed)	DSD	km/hr		
12	THRESHOLD(Direction Angle)	TDA	radians	1.57	
12	THRESHOLD(Hail #1)	TH1	km	8	
12	THRESHOLD(Hail #2)	TH2	dBZe	55	
12	THRESHOLD(Hail #4)	TH4	radians	.785-3.14	
12	THRESHOLD(Hail #5)	TH5	dBZe	50	
12	THRESHOLD(Hail #6)	TH6	km	4	
12	THRESHOLD(Hail Height)	THA	km	5-12	
12	THRESHOLD(Hail High/Low)	THL	km	5	
12	THRESHOLD(Hail Low)	THW	km	5	
12	THRESHOLD(High Confidence)	THC	unitless	50	
12	THRESHOLD(High Reflectivity)	TR	dBZe	70	

12	THRESHOLD(High Score)	THI	unitless	60	
12	THRESHOLD(Low Confidence)	TLC	unitless	25	
12	THRESHOLD(Score)	TSC	unitless	50	
12	WEIGHT	WGT	unitless	17, 15, 7, 8	
12	WEIGHT(Con't)	WGT(Con't)	Unitless	20, 18	
15	SEVERE WEATHER COEFFICIENTS	SW1-SW6	unitless		6.90, 7.39, .22, 3.67, .01, 2.55
15	SWP BOX SIZE	SBS	km		28 x 28 to 44 x 44
17	ELEVATION/RANGE/AZIMUTH BOUNDARIES	ERB	see algorithm		see algorithm
17	ELEVATION/RANGE/AZIMUTH BOUNDARIES--cont.	ERB	see algorithm		see algorithm
17	OCCULTATION CODES	OC	unitless		
17	RANGE(Tilt Test)	RTT	km	40:150	
17	REFLECTIVITY(Tilt Test)	ZTT	dBZe		1.0/0-10
17	maximum AREA(percent reduction)	APRmax	percent		50/25-75
17	maximum RANGE(Bi-Scan)	RBSmax	km		230/50-230
17	maximum THRESHOLD(Reflectivity-1)	THRmax1	dBZe		70/60-70
17	minimum AREA(Echo)	AEmin	km**2		600
17	minimum REFLECTIVITY(Area-Averaged)	ZAVmin	dBZe		10.0
17	minimum THRESHOLD(Reflectivity-1)	THRmin1	dBZe		18
18	BOX(1/4 LFM Grid)	BLG	N/A		
18	COEFFICIENT(Multiplicative Z-R)	CZM	unitless	300	
18	COEFFICIENT(Z-R Power)	CZP	unitless	1.4	
18	COEFFICIENTS(Range Effect)	CO1	dBR		
18	COEFFICIENTS(Range Effect)	CO2	unitless		
18	COEFFICIENTS(Range Effect)	CO3	unitless		
18	PARAMETER(Time Continuity #1)	P1	1/hr		24.0
18	PARAMETER(Time Continuity #2)	P2	1/hr		13.2
18	RANGE(Cut-Off)	RCO	km		150
18	RATE(Zero Precipitation)	RZP	dBR		-17.5
18	THRESHOLD(Max Time Difference)	TMT	hr	0.25	
18	maximum RATE(Echo Area Change)	RACmax	km**2/hr		20,700.0
18	maximum SPEED(Storm)	SSmax	km/hr		90/50-150
18	minimum AREA(Time Continuity)	ATCmin	km**2		200
19	ACCUMULATION(Zero Hourly)	AZH	dBA		-18
19	THRESHOLD(Hourly Outlier)	THO	dBA		26.0
19	ending TIME(Gage Accumulation)	TGAend	N/A		
19	maximum TIME(Interpolation)	TIPmax	hours	0.5	0.25-1.0
19	minimum TIME(Period)	TPEmin	hours	0.9	0.75-1.0
20	ACCUMULATION(Zero Hourly)	AZH	dBA		-18
20	SYSTEM NOISE	SYS	unitless		0.05
20	THRESHOLD(Gage Discard)	TGD	unitless		2.0
20	THRESHOLD(Number of Sets)	TNS	unitless		2-10
20	THRESHOLD(Time Difference)	TTD	hours		0.5/0.1-1.0
20	TIME(Bias Estimation)	TBE	absolute time		0.8/0.6-0.9
20	VARIANCE ADJUSTMENT FACTOR	VAF	unitless		0.5/0-10
20	ending TIME(Gage Accumulation)	TGAend	absolute time		0.5/0.25-0.75
20	maximum MEAN SQUARE ERROR	MSEmax	unitless		0.8
20	maximum TIME(Propagation)	TPRmax	hours		24.0/6.0-48.0
20	reset BIAS	Bres	unitless		1.0
20	reset MEAN SQUARE ERROR	MSEres	unitless		0.5
21	ACCUMULATION(Zero Hourly)	AZH	dBA		-18
21	BOX(1/40 LFM Grid)	BLM	N/A		
21	BOX(2 km x 2 km Grid)	BX	N/A		
21	IDENTIFIER INFORMATION	ID	N/A		
21	SUPPLEMENTAL DATA	SUP	N/A		
21	TIMES(Three Hour Product Generator)	TPG	hr		0-23 inclusive

22	MASS MULTIPLICATIVE FACTOR	MMF	(mm**6/m**3)	486	
22	MASS MULTIPLICATIVE FACTOR(Con't)	MMF(Con't)	(hr/mm)**PIE		
22	MASS WEIGHTED FACTOR	MWF	(hr)(kg)/km**4)	53x10**9	
22	PRECIPITATION INTENSITY EXPONENT	PIE	N/A	1.37	
22	REFLECTIVITY AVERAGING FACTOR	ZU	unitless	3	
22	THRESHOLD(Dropout Number)	TDN	unitless	2	
22	THRESHOLD(Dropout Reflectivity)	TDR	dBZe	25	
22	THRESHOLD(Minimum Reflectivity-2)	THR2	dBZe	30	
22	THRESHOLD(Segment Length)	TSL	km	4.2	5
23	TURBULENCE THRESHOLD(Moderate)	TTmod	km**2/3/hr	6.683888	
23	TURBULENCE THRESHOLD(Severe)	TTsvr	km**2/3/hr	13.367776	
23	TURBULENCE(Outer Scale)	TOS	km	2	1-4
24	THRESHOLD(Azimuth)	TAZ	radians	0.035	
24	THRESHOLD(Divergence Range)	TDI	km		3.5
24	THRESHOLD(Divergence-High Shear)	TDHS	1/hr	7.2	
24	THRESHOLD(Divergence-Low Shear)	TDLS	1/hr	3.6	
24	THRESHOLD(Height)	THH	km	8	
24	THRESHOLD(High Flux)	THF	1/hr	108	
24	THRESHOLD(Low Flux)	TLF	1/hr	36	
24	THRESHOLD(Pattern Vector Number)	TPN	unitless	6	
24	THRESHOLD(Velocity Reflectivity)	TVR	dBZe	15	
26	SEARCH PERCENTAGE	PCT	unitless	.05	.05
26	THRESHOLD(TVS Shear)	TTV	1/hr	180	
27	AZIMUTH(Filtered Velocities)	AFL	radians		
27	DATA(Bad)	DTB	unitless		
27	FREQUENCY(Cutoff)	FCO	unitless		0.15
27	GAP(Maximum)	GAPmax	radians		
27	INTERVAL(Average)	INA	km	6.75	
27	INTERVAL(Class)	INC	m/s		
27	INTERVAL(Width)	INW	km/hr	7.2	
27	NUMBER(Weights)	NWT	unitless	51	
27	RANGE INTERVAL	RNT	km	6.75	
27	VELOCITY(Minimum Number)	VNM	unitless		
29	MAXIMUM FEATURE DISTANCE	MFDI	km	5	
29	THRESHOLD (PATTERN VECTOR (Radial) Number)	TVVN	unitless	10	
29	THRESHOLD(Convergence Azimuth)	TCA	degrees	4	
29	THRESHOLD(Convergence Range)	TCR	km	4.0	
29	THRESHOLD(High Covergence Flux)	THCF	km**2/hr	27.8	
29	THRESHOLD(High Gradient)	THG	1/hr	0.181	
29	THRESHOLD(Low Convergence Flux)	TLCF	km**2/hr	8.34	
29	THRESHOLD(Low Gradient)	TLG	1/hr	0.139	
29	THRESHOLD(Velocity Number)	TVN	km/hr	5	
29	THRESHOLD(Velocity Reflectivity)	TVR	dBZe	15	
30	BOX(1/40th LFM Grid)	BLM	N/A		
30	ERROR(Proportion Factor)	EPF	unitless		
30	PROJECTION INTERVAL	LPR	hr		0.5-2.0
30	STORM INITIATION DECAY	SID	unitless		0.8-1.0
30	STORM INITIATION WIDTH	D	grid spacing		1-2
30	THRESHOLD(minimum NUMBER of SAMPLES)	TMN	N/A		
30	TIME(Reset)	TRT	hr		1-2
33	DOMAIN(Resolution)	DOR	km		0.5-4.0
33	DOMAIN(X Minimum)	DXM	km		
33	DOMAIN(X Size)	DXS	km		230
33	DOMAIN(Y Minimum)	DYM	km		
33	DOMAIN(Y Size)	DYS	km		230

33	NUMBER(Filter)	NFL	unitless	9	
33	NUMBER(Sample Volumes)	NSV	unitless	3	
33	THRESHOLD(Combined Shear)	THCS	1/hr		8-16
33	THRESHOLD(Number)	NTH	unitless	.75	
33	THRESHOLD(Velocity Power)	TPOW	dB	5-10	
34	LENGTH(Correlation Box)	LEC	km	28.0	
34	SPACING(Correlation Box)	SPC	km	28.0	20.0-28.0
34	SPEED(Storm Limit)	SPL	km/hr	120	80-120
34	THRESHOLD(Correlation)	THCO	N/A	.55	0.50-0.70
34	THRESHOLD(Pixel Fraction)	TPF	N/A	0.25	0.15-0.30
34	THRESHOLD(dBZe)	THDB	dBZe	25.0	20.0-35.0
34	TYPE(Layer'	TYLA	unitless	see algo	see algorithm

NOTE: In algorithm #33, the Cartesian grid box described by DOMAIN(X Size) and DOMAIN(Y Size) should be centered on the radar.

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